

PB85-122133

Nationwide Urban Runoff Program, Washington, DC  
Area Urban Runoff Project: Final Report

Metropolitan Washington Council of  
Governments, DC

Prepared for

Environmental Protection Agency, Washington, DC

Dec 83



U.S. Department of Commerce  
National Technical Information Service

**NTIS**

FB85-122133

URBAN RUNOFF IN THE  
WASHINGTON METROPOLITAN AREA

FINAL REPORT  
WASHINGTON, D.C. AREA  
URBAN RUNOFF PROJECT

Prepared for

U.S. EPA Nationwide Urban Runoff Program  
under U.S. EPA Grant No. PO-003208-01

Prepared by

Department of Environmental Programs  
Metropolitan Washington Council of Governments

in association with the  
Northern Virginia Planning District Commission  
and  
Virginia Polytechnic Institute and State University  
(Occoquan Watershed Monitoring Laboratory)

on behalf of the  
Washington Metropolitan Water Resources Planning Board

December 1983

REPRODUCED BY  
NATIONAL TECHNICAL  
INFORMATION SERVICE  
U.S. DEPARTMENT OF COMMERCE  
SPRINGFIELD, VA. 22161



**COG Project Staff**

**Department of Environmental Programs**

Austan S. Librach, Director  
Cameron Wiegand, Project Manager  
Thomas R. Schueler, Principal Analyst and Author  
Michael P. Sullivan, Senior Engineer  
Robert Magill, Planner  
Sherry J. Tyree, Secretary III  
Patricia A. Warren, Administrative Aide  
Dolores Brandow, Graphics

# NOTICE

THIS DOCUMENT HAS BEEN REPRODUCED  
FROM THE BEST COPY FURNISHED US BY  
THE SPONSORING AGENCY. ALTHOUGH IT  
IS RECOGNIZED THAT CERTAIN PORTIONS  
ARE ILLEGIBLE, IT IS BEING RELEASED  
IN THE INTEREST OF MAKING AVAILABLE  
AS MUCH INFORMATION AS POSSIBLE.

|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |                      |                                                         |                                                                    |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------|---------------------------------------------------------|--------------------------------------------------------------------|
| <b>REPORT DOCUMENTATION PAGE</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     | <b>1. REPORT NO.</b> | <b>2.</b>                                               | <b>3. Recipient's Accession No.</b><br>PB85-122133                 |
| <b>4. Title and Subtitle</b><br>Nationwide Urban Runoff Program, Washington, D.C. Area Urban Runoff Project, <u>FINAL REPORT</u> .                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |                      |                                                         | <b>5. Report Date</b><br>December, 1983                            |
| <b>7. Author(s)</b> Department of Environmental Programs<br>Metropolitan Washington Council of Governments/W.R. Planning Bd.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |                      |                                                         | <b>8. Performing Organization Rept. No.</b>                        |
| <b>9. Performing Organization Name and Address</b><br>Metropolitan Washington Council of Governments<br>1875 Eye Street, N.W., Suite 200<br>Washington, D.C. 20006                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |                      |                                                         | <b>10. Project/Task/Work Unit No.</b>                              |
| <b>12. Sponsoring Organization Name and Address</b><br>EPA, Office of Water Program Operations<br>Water Planning Division<br>401 M Street, SW<br>Washington, D C 20460                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |                      |                                                         | <b>11. Contract(C) or Grant(G) No.</b><br>(C)<br>(G) P 003208-01   |
| <b>15. Supplementary Notes</b><br><br>This is one of several individual reports completed by MWCOC under this grant.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |                      |                                                         | <b>13. Type of Report &amp; Period Covered</b><br>Final, 1979-1983 |
| <b>16. Abstract (Limit: 200 words)</b> This report summarized the principal findings and conclusions derived from the following five major research areas;<br><br>(1) Identifying the principal water quantity and water quality impacts of urban stormwater runoff within the D.C. metropolitan area;<br><br>(2) Evaluating the pollutant removal capability of various urban best management practices (BMPs) currently in use within the region; and identifying BMP design features which have the greatest influence on pollutant removal capability;<br><br>(3) Developing a predictive methodology for estimating the costs of building and maintaining stormwater ponds so that the comparative costs of various kinds of stormwater ponds could be evaluated;<br><br>(4) Examining the importance of atmospheric deposition as a source of pollutants which can be eventually delivered in urban runoff, and to evaluate the effectiveness of source controls in reducing this supply; and (5) Developing and applying sophisticated watershed modeling tools to integrate NURP research into a coherent framework, so as to identify cost-effective runoff management strategies in developing watersheds. |                      |                                                         |                                                                    |
| <b>17. Document Analysis</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |                      |                                                         |                                                                    |
| <b>a. Descriptors</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |                      |                                                         |                                                                    |
| Hydrology                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            | Water pollution      | Storms                                                  | Civil Engineering                                                  |
| Urban development                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    | Water resources      | Regional planning                                       |                                                                    |
| Watersheds                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | Sedimentation        | Urban planning                                          |                                                                    |
| <b>b. Identifiers/Open-Ended Terms</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |                      |                                                         |                                                                    |
| Runoff                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | Soil Erosion         | Storm Drains                                            |                                                                    |
| Streamflow                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | Water Quality        | Urbanization                                            |                                                                    |
| Stream pollution                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     | Sediments            | Land use                                                |                                                                    |
| Rainfall                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | Sediment Transport   |                                                         |                                                                    |
| Snowmelt                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | Suspended Solids     |                                                         |                                                                    |
| <b>18. Availability Statement:</b> No restriction on distribution.<br>Available from National Technical Information Service, Springfield, VA 22161                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |                      | <b>19. Security Class (This Report)</b><br>UNCLASSIFIED | <b>21. No. of Pages</b><br>199                                     |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |                      | <b>20. Security Class (This Page)</b><br>UNCLASSIFIED   | <b>22. Price</b>                                                   |

# TABLE OF CONTENTS

|                                                                                | Page |
|--------------------------------------------------------------------------------|------|
| List of Figures .....                                                          | vi   |
| List of Tables .....                                                           | ix   |
| PREFACE .....                                                                  | xiii |
| EXECUTIVE SUMMARY .....                                                        | xvii |
| I. OVERVIEW OF WASHINGTON NURP PROJECT .....                                   | 1.1  |
| Introduction .....                                                             | 1.1  |
| Focus of Study .....                                                           | 1.1  |
| Principal Project Participants and Their Roles .....                           | 1.2  |
| Background Discussion of Washington NURP<br>Study Area .....                   | 1.3  |
| Regional Directions in Runoff Control .....                                    | 1.6  |
| Summary of the NURP Monitoring Program .....                                   | 1.8  |
| BMP Cost Evaluations .....                                                     | 1.12 |
| Data Base Summary .....                                                        | 1.13 |
| Organization of Report .....                                                   | 1.14 |
| II. POLLUTANT REMOVAL CAPABILITIES OF<br>URBAN BEST MANAGEMENT PRACTICES ..... | 2.1  |
| Introduction .....                                                             | 2.1  |
| Methods for Monitoring BMPs .....                                              | 2.11 |
| Methods Used for Analyzing BMP Pollutant<br>Removal Efficiencies .....         | 2.14 |
| Results of BMP Effectiveness Analysis .....                                    | 2.17 |
| Dry Stormwater Ponds .....                                                     | 2.17 |
| Extended Detention Dry Ponds .....                                             | 2.17 |
| Wet Ponds .....                                                                | 2.19 |
| Grassed Swales .....                                                           | 2.22 |
| Infiltration Controls .....                                                    | 2.23 |
| Porous Pavement .....                                                          | 2.24 |
| General Design Features Which Enhance<br>Pollutant Removal .....               | 2.25 |
| Detention Time .....                                                           | 2.25 |
| Pond Bed Design .....                                                          | 2.27 |
| Infiltration/Contact Time .....                                                | 2.29 |
| Biological Removal .....                                                       | 2.29 |
| Additional Comments .....                                                      | 2.33 |

|                                                                               |      |
|-------------------------------------------------------------------------------|------|
| Conclusions and Recommendations .....                                         | 2.34 |
| References .....                                                              | 2.37 |
| III. COSTS OF BEST MANAGEMENT PRACTICES:<br>STORMWATER MANAGEMENT PONDS ..... |      |
| Introduction .....                                                            | 3.1  |
| Cost Factors Considered .....                                                 | 3.1  |
| Types of Ponds Considered .....                                               | 3.2  |
| Methodology .....                                                             | 3.5  |
| Base Construction Costs .....                                                 | 3.5  |
| Contingency Related Costs .....                                               | 3.8  |
| Pond Operation and Maintenance Costs .....                                    | 3.8  |
| Sediment Removal .....                                                        | 3.9  |
| Long Term Financing .....                                                     | 3.11 |
| Results .....                                                                 | 3.11 |
| Base Construction Costs .....                                                 | 3.11 |
| Extended Detention Dry Ponds .....                                            | 3.13 |
| Wet Ponds .....                                                               | 3.13 |
| Pond Operation and Maintenance .....                                          | 3.16 |
| Computation of Total Pond Costs .....                                         | 3.17 |
| Conclusions .....                                                             | 3.21 |
| References .....                                                              | 3.23 |
| IV. ATMOSPHERIC LOADING SOURCES .....                                         |      |
| Introduction .....                                                            | 4.1  |
| Interactions Between Air and Water Quality .....                              | 4.1  |
| Issues Addressed by Study .....                                               | 4.1  |
| Methods for Monitoring Atmospheric Sources .....                              | 4.3  |
| Atmospheric Deposition .....                                                  | 4.3  |
| TSP Monitoring .....                                                          | 4.5  |
| Results of Atmospheric Source Monitoring Study .....                          | 4.7  |
| Average Annual Deposition Rates .....                                         | 4.7  |
| Relative Importance of Wetfall and Dryfall Loads .....                        | 4.9  |
| Variability in Atmospheric Loadings .....                                     | 4.12 |
| Composition of Airshed .....                                                  | 4.15 |
| Acid Precipitation .....                                                      | 4.18 |
| Relation Between Deposition and Runoff Quality .....                          | 4.19 |
| Major Sources of Atmospheric Pollutants .....                                 | 4.21 |
| Benefits of Source Controls .....                                             | 4.21 |
| Conclusions .....                                                             | 4.24 |
| References .....                                                              | 4.26 |



|                                                            |      |
|------------------------------------------------------------|------|
| V. SPECIAL URBAN RUNOFF STUDIES .....                      | 5.1  |
| Priority Pollutant Scan .....                              | 5.3  |
| Central Business District Loading Study .....              | 5.7  |
| Trace Metal Accumulation and Movement .....                | 5.11 |
| Grassed Swales .....                                       | 5.11 |
| Stormwater Basins .....                                    | 5.13 |
| Bioavailability of Nutrients in Runoff .....               | 5.17 |
| Effect of BMPs .....                                       | 5.17 |
| Settling behavior of Runoff Pollutants .....               | 5.18 |
| Summary .....                                              | 5.21 |
| References .....                                           | 5.23 |
| VI. PROTOTYPE NONPOINT SOURCE MANAGEMENT STUDIES .....     | 6.1  |
| Introduction .....                                         | 6.1  |
| Prototype Watershed Planning Approach .....                | 6.3  |
| Water Quality Monitoring .....                             | 6.3  |
| Model Development .....                                    | 6.5  |
| Model Application Phase I .....                            | 6.10 |
| Model Application Phase II .....                           | 6.10 |
| Economic Analysis .....                                    | 6.14 |
| Study Integration .....                                    | 6.16 |
| Seneca Creek Watershed Study Findings .....                | 6.18 |
| Piscataway Creek Watershed Study Findings .....            | 6.25 |
| Regional Implications of Prototype Watershed Studies ..... | 6.30 |
| References .....                                           | 6.35 |

## LIST OF FIGURES

| Figure                                                                                                                                    | Page |
|-------------------------------------------------------------------------------------------------------------------------------------------|------|
| 1.1 Metropolitan Washington Streams and Principal Watersheds .....                                                                        | 1.4  |
| 1.2 Location of NURP Monitoring Sites .....                                                                                               | 1.9  |
| 2.1 Monitoring Setup for Urban BMP Sampling .....                                                                                         | 2.12 |
| 2.2 Methods Used to Calculate Pollutant Removal Efficiency of Urban BMPs .....                                                            | 2.15 |
| 2.3 Comparison of Independent Methods Used to Calculate Removal Efficiencies of Dry Pond BMPs .....                                       | 2.18 |
| 2.4 Pollutant Removal Efficiencies Associated with Selected Stormwater Pond BMPs: Nutrients .....                                         | 2.18 |
| 2.5 Comparative Pollutant Removal Efficiency of Wet and Extended Detention Stormwater Ponds .....                                         | 2.20 |
| 2.6 Relationship Between Storm Size and Sediment Removal .....                                                                            | 2.20 |
| 2.7 Comparisons of Independent Methods Used to Calculate Removal Efficiencies of Wet Stormwater Pond BMPs .....                           | 2.21 |
| 2.8 Comparative Pollutant Removal Performance of Porous Pavement and Infiltration Trench BMPs .....                                       | 2.21 |
| 2.9 Relationship Between Sediment Removal Rate, Influent Concentration and Sedimentation Time: Experimental Settling Column Studies ..... | 2.26 |
| 2.10 Removal Rates Observed in Experimental Settling Column Studies: Removal After 6 and 48 Hours of Detention ...                        | 2.26 |
| 2.11 Comparative Pollutant Removal After Six Hours: Experimental and Field Measurements of Extended Detention .....                       | 2.28 |
| 2.12 Estimated Diversions to Groundwater in Selected Volume Control BMPs .....                                                            | 2.30 |
| 2.13 Relationship Between Median Removal Rate and Duration of Runoff Within Volume Control BMPs .....                                     | 2.30 |
| 2.14 Comparative Performance of Wet and Dry Stormwater Management Ponds in Washington Area NURP Project .....                             | 2.31 |
| 2.15 Effect of Wet Pond Area on Long Term Removal Efficiency .....                                                                        | 2.31 |
| 3.1 Schematic of Stormwater Management Ponds .....                                                                                        | 3.3  |
| 3.2 Montgomery County Stormwater Pond Storage Requirements Two-Year Storm Design .....                                                    | 3.4  |



|     |                                                                                                                                      |      |
|-----|--------------------------------------------------------------------------------------------------------------------------------------|------|
| 3.3 | Log Plot of Average Stormwater Management Pond Construction Cost Estimates vs. Volume of Storage ....                                | 3.12 |
| 3.4 | Observed vs. Calculated Pond Construction Costs .....                                                                                | 3.12 |
| 3.5 | Comparison of Annual Total Pond Costs<br>Dry Pond, Extended Detention Dry Pond, Wet Pond .....                                       | 3.20 |
| 4.1 | Simplified Representation of the Dynamic Interaction<br>Of Air and Water Quality Processes .....                                     | 4.2  |
| 4.2 | Location of Wetfall/Dryfall Monitors .....                                                                                           | 4.6  |
| 4.3 | Location of Hi-Vol TSP Air Quality Samplers .....                                                                                    | 4.6  |
| 4.4 | Comparative Atmospheric Deposition Rates Between<br>Rural, Suburban and Urban Stations .....                                         | 4.10 |
| 4.5 | Minimum and Median Precipitation pH Measurements<br>Rural, Suburban and Urban Stations .....                                         | 4.17 |
| 4.6 | Comparison of Atmospheric and Runoff Nonpoint<br>Loads in Highly Impervious Areas .....                                              | 4.20 |
| 5.1 | Regional Locations of Small Test Watersheds Used to<br>Develop Nonpoint Loading Rates:<br>NURP and 208 Studies .....                 | 5.8  |
| 5.2 | Location of Soil Metal BMP Sampling Sites in the<br>Washington Metropolitan Area .....                                               | 5.10 |
| 5.3 | Sampling Protocols Employed in Soil Metal Study .....                                                                                | 5.12 |
| 5.4 | Relationship Between Zinc Concentration in Runoff and<br>Downstream Distance From Culvert Outlet at Two<br>Grassed Swale Sites ..... | 5.14 |
| 5.5 | Iso-Concentration Maps of Trace Metal Distributions<br>In the Sediments of the Bulk Mail Stormwater Pond ....                        | 5.15 |
| 5.6 | Pollutant Removal Achieved After 6 and 48 Hours<br>of Extended Detention: Experimental Settling<br>Column Studies .....              | 5.19 |
| 5.7 | Sediment Settling Rates Observed at Differing<br>Influent Concentrations .....                                                       | 5.19 |
| 6.1 | Locations of Seneca and Piscataway<br>Creek Watersheds .....                                                                         | 6.2  |
| 6.2 | A Prototype Approach for Watershed Planning .....                                                                                    | 6.4  |
| 6.3 | Comparison of Observed and Simulated Annual Runoff<br>Volumes Recorded at Dawsonville, Md (Seneca Creek)<br>1967-1975 .....          | 6.8  |
| 6.4 | Observed and Simulated Storm Sediment Yields at<br>Dawsonville, Md (Seneca Creek) 1980-1981 .....                                    | 6.8  |

|     |                                                                                                                                         |      |
|-----|-----------------------------------------------------------------------------------------------------------------------------------------|------|
| 6.5 | Observed and Simulated Storm Total Phosphorus Loadings at Piscataway Creek NURP Monitor: 1980-1981 .....                                | 6.9  |
| 6.6 | Continuous Simulation of Instream Dissolved Oxygen Levels Riffleford Road, Md (Seneca Creek) Summer, 1974 .....                         | 6.9  |
| 6.7 | Projected Mean Annual Chlorophyll "a" Levels in Little Seneca Lake Under Future Land Use Scenarios and Differing Control Programs ..... | 6.11 |
| 6.8 | Relative Water Quality Index Used to Screen Land Use and Runoff Control Options .....                                                   | 6.15 |
| 6.9 | Cost-Benefit Curves Associated with Various Control Options and Future Land Use Scenarios in the Clarksburg Planning Area .....         | 6.17 |

## LIST OF TABLES

| Table                                                                                             | Page |
|---------------------------------------------------------------------------------------------------|------|
| 1.1 Land Cover in the Washington Metropolitan Area .....                                          | 1.5  |
| 1.2 Average Annual Surface Runoff Simulated for Urban and Rural Land Uses by Soil Texture .....   | 1.7  |
| 1.3 Water Quality Measurements: Washington NURP Project .....                                     | 1.10 |
| 1.4 Selected Site Characteristics of Land Surfaces Monitored Under Washington NURP Project .....  | 1.10 |
| 1.5 Coverage of Washington NURP and 208 Monitoring Data by Land Use .....                         | 1.13 |
| 1.6 Technical Reports Issued on Aspects of the Washington NURP Project .....                      | 1.15 |
| 2.1 Site Selection Criteria for Urban BMP Monitoring .....                                        | 2.4  |
| 2.2 BMP Fact Sheet: Lakeridge Dry Stormwater Pond .....                                           | 2.5  |
| 2.3 BMP Fact Sheet: Stedwick Extended Detention Stormwater Pond .....                             | 2.5  |
| 2.4 BMP Fact Sheet: Burke Wet Stormwater Pond .....                                               | 2.6  |
| 2.5 BMP Fact Sheet: Westliegh Wet Stormwater Pond .....                                           | 2.6  |
| 2.6 BMP Fact Sheet: Fair Oaks Wet Stormwater Pond .....                                           | 2.7  |
| 2.7 BMP Fact Sheet: Dufief Grassed Roadside Swale .....                                           | 2.7  |
| 2.8 BMP Fact Sheet: Fairridge Grassed Roadside Swale .....                                        | 2.8  |
| 2.9 BMP Fact Sheet: Stratton Woods Grassed Roadside Swale .....                                   | 2.8  |
| 2.10 BMP Fact Sheet: Burke Village Infiltration Trench .....                                      | 2.9  |
| 2.11 BMP Fact Sheet: Dandridge Infiltration Pit .....                                             | 2.9  |
| 2.12 BMP Fact Sheet: Rockville Porous Pavement .....                                              | 2.10 |
| 2.13 Water Quality Parameters Monitored in the BMP Effectiveness Study .....                      | 2.13 |
| 2.14 Citizen Attitudes Towards Stormwater Basins .....                                            | 2.32 |
| 3.1 Sample Estimate of Pond Construction Costs Based on Unit Costs (180,000 Cu Ft Dry Pond) ..... | 3.6  |
| 3.2 Characteristics of Ponds Selected for Cost Analysis ....                                      | 3.7  |
| 3.3 Organizations Utilized in O&M Cost Analysis .....                                             | 3.9  |

|     |                                                                                                                                                         |      |
|-----|---------------------------------------------------------------------------------------------------------------------------------------------------------|------|
| 3.4 | Reported Pond Maintenance Activities .....                                                                                                              | 3.10 |
| 3.5 | Incremental Costs of Modified Detention Pond<br>Construction .....                                                                                      | 3.14 |
| 3.6 | Comparison of Wet vs. Dry Pond Construction Costs .....                                                                                                 | 3.15 |
| 3.7 | Projected Construction and Maintenance Costs<br>of Dry Detention Ponds - 20 and 100 Acre Developments<br>Fairfax County 10-Year Design Criteria .....   | 3.18 |
| 3.8 | Projected Construction and Maintenance Costs<br>of Dry Detention Ponds - 20 and 100 Acre Developments<br>Montgomery County 2-Year Design Criteria ..... | 3.19 |
| 4.1 | Parameters Analyzed in Atmospheric Source<br>Loading Investigations .....                                                                               | 4.4  |
| 4.2 | Average Annual Atmospheric Pollutant Loadings<br>in the Washington Area .....                                                                           | 4.8  |
| 4.3 | Mean Concentration of Pollutants in Hi-Vol<br>TSP Filters: Lumped Data (ug/m3) .....                                                                    | 4.16 |
| 4.4 | Mean Concentration of Pollutants in Hi-Vol<br>TSP Filters: Synoptic Events (ug/m3) .....                                                                | 4.16 |
| 4.5 | Comparison of Mean Regional TSP Enrichment<br>Levels Between the Summer of 1976 and 1980 .....                                                          | 4.17 |
| 4.6 | Dominant Sources of Atmospheric Pollutants<br>in the Washington Metropolitan Airshed .....                                                              | 4.22 |
| 4.7 | Evaluation Framework for Identifying Possible<br>Positive Water Quality Spinoff Benefits From Air<br>Quality Emission Controls .....                    | 4.23 |
| 5.1 | U.S. EPA Priority Pollutant List .....                                                                                                                  | 5.2  |
| 5.2 | Priority Pollutants Detected in Washington Area<br>Urban Runoff Samples .....                                                                           | 5.4  |
| 5.3 | Trace Metals Detected in Urban Runoff<br>Toxicant Scan .....                                                                                            | 5.6  |
| 5.4 | Comparison of Suburban and Downtown Central<br>Business District Catchments .....                                                                       | 5.10 |
| 5.5 | Comparative Trace Metal Content of Stormwater<br>Basin Sediments and Regionally Produced Study .....                                                    | 5.16 |
| 6.1 | Major Processes Simulated and Key Outputs<br>Derived From the HSPF Model .....                                                                          | 6.6  |
| 6.2 | Control Strategies Examined by the Seneca<br>Model in the Clarksburg Planning Area .....                                                                | 6.13 |
| 6.3 | Existing and Future Land Use Distributions<br>in Seneca and Piscataway Creek Watersheds .....                                                           | 6.19 |

|     |                                                                                                           |      |
|-----|-----------------------------------------------------------------------------------------------------------|------|
| 6.4 | Water Quality and Quantity Projections in<br>Piscataway Creek Under Different Land Use<br>Scenarios ..... | 6.27 |
| 6.5 | Cost of Runoff Controls in the Piscataway<br>Creek Watershed .....                                        | 6.29 |
| 6.6 | Characteristics of Local Stormwater Management<br>Programs in the Washington Metropolitan Area .....      | 6.31 |
| 6.7 | Regional Progress in Stormwater Management: 1982 .....                                                    | 6.32 |



## PREFACE

In 1978, the United States Environmental Protection Agency initiated a multi-year study to examine the significance of urban runoff as a component of the nation's water pollution problems, along with the need and potential for its control. The study, termed the Nationwide Urban Runoff Program or NURP, was designed to build on the limited body of knowledge then available on the impacts of urban runoff on receiving waters, and to develop practical engineering data on the relative cost and effectiveness of control measures.

EPA structured its NURP effort to develop information on various aspects of urban runoff from 28 separate urban project areas. These projects were geographically dispersed throughout the country in the attempt to collect data broadly representative of the range of variability in climate, soils, geology, and development conditions which interactively affect urban runoff quality from the nation's diverse urban areas. While the focus of each local NURP project was separate and distinct, most shared certain common research objectives aimed at characterizing pollutant types, loads, receiving water effects, alternative control measures, and their overall cost-effectiveness.

In 1979, EPA accepted a proposal from the Metropolitan Washington Water Resources Planning Board (WRPB) to conduct a NURP demonstration project in the Washington, D.C. metropolitan area. The four year study which ensued was conducted and coordinated on behalf of the WRPB by the Metropolitan Washington Council of Governments (COG), in association with the Northern Virginia Planning District Commission (NVPDC) and the Virginia Polytechnic Institute and State University (VPI & SU). This Final Report represents the culmination of that effort.

While EPA provided the primary funding support for the Washington NURP project, local governments and the business community provided matching funds, staff services and other material support. In particular, the Montgomery County Department of Transportation (MC/DOT) and the Washington Suburban Sanitary Commission (WSSC) designed and built experimental stormwater pond structures for pollutant removal analysis. Staff of the Maryland National Capital Park and Planning Commission (M-NCPPC) provided invaluable support and guidance for the prototype watershed management studies. Public works officials from COG's 16 member jurisdictions assisted in the design of the study and the selection of monitoring sites. The National Association of Home Builders (NAHB) and the Northern Virginia Builders Association (NVBA) provided financial support to the project. In addition, both associations participated closely in the selection of monitoring sites and the development of stormwater pond cost estimates. Further technical guidance on the overall study design was supplied by the WRPB's Nonpoint Source Task Force (NPSTF) - composed of engineers and planners from local and state governments, as well as from the business community and area citizen groups.

The unique perspectives that each of these individuals and organizations brought to bear were invaluable in helping to define the nature of local urban runoff problems, and identifying pragmatic approaches for their effective management. On behalf of the WRPB, COG staff would like to acknowledge the close cooperation and diligent efforts of all project participants.

COG staff would like to specifically express its appreciation to a number of individuals whose ideas and energies materially shaped the entire project. Particular thanks go to Dr. Thomas Grizzard of the Occoquan Watershed Monitoring Laboratory (CWML) of VPI&SU for installing and operating one of the largest urban runoff field monitoring efforts ever conducted in the country. The tireless efforts of Jay Lanier and other CWML field monitoring and laboratory personnel, often under adverse conditions and over long distances are also appreciated. Dr. Grizzard and his graduate students also conducted special laboratory research and analytical studies which assisted in the development of conclusions on the pollutant removal efficiencies of various urban runoff controls. Similar thanks are conveyed to Jack Hartigan, Tom Quasebarth, Dave Biggars and John Freedman of NVPDC who performed the difficult task of analyzing and interpreting certain aspects of the urban runoff database.

COG staff also wishes to recognize the invaluable assistance provided by the following people:

|                                                       |                                                                                        |
|-------------------------------------------------------|----------------------------------------------------------------------------------------|
| EPA Headquarters                                      | Dennis Athayde                                                                         |
| EPA Region III                                        | Larry Merrill                                                                          |
| District of Columbia Government                       | William Garlow<br>Rudy Gutierrez                                                       |
| Fairfax County Government                             | Col. William Smith<br>Bruce Douglas<br>Jack White                                      |
| Montgomery County Government                          | David Sobers<br>Phillip Bennett<br>David Waggaman<br>Robert Merryman<br>Lewis Williams |
| Prince William County Government                      | Nimet R. El Alaily<br>Leslie Figirero                                                  |
| Prince George's County Government                     | Edmund Piesen                                                                          |
| City of Rockville                                     | Rod LaFever                                                                            |
| U.S. National Capital Park and<br>Planning Commission |                                                                                        |
| (Montgomery Parks Dept.)                              | Stanton Ernst<br>J. L. Jalali                                                          |
| (Montgomery Planning Dept.)                           | Jorge Valladares<br>Nazir Baig<br>Melissia Bainach<br>John Galli                       |
| (Prince George's Planning Dept.)                      | Nick Motta                                                                             |
| Washington Suburban Sanitary<br>Commission            | Edward Graham<br>Diane Lucci                                                           |
| National Assoc. of Home Builders                      | Richard Morrison<br>Dave Johnson (former staff)<br>Charles Gornes (former staff)       |
| Northern Virginia Builders Assoc.                     | Robert Johnson<br>Brad Crockett                                                        |
| Suburban Maryland Home Builders                       | Steve Eckert<br>Michael Thompson                                                       |
| Former COG Staff                                      | Robert Bragan<br>Walter Bialas<br>Vincent Cipriani<br>George DeBuchannane              |
| JTC, Associates                                       | Dr. John Cookson                                                                       |
| O'Brien and Gere Inc.                                 | Greg Walter                                                                            |

## **EXECUTIVE SUMMARY**

## EXECUTIVE SUMMARY

Over the past few decades there has been a growing recognition of the need to control increases in stormwater runoff that accompany urban and suburban development. In the Washington area, this has been manifested through substantial commitments of resources by area governments aimed primarily at reducing localized flooding and erosion problems. More recently, the scientific community has also begun to investigate the potential impacts of urban runoff on water quality and stream habitat conditions. This report addresses the water quality aspects of urban runoff in the Washington area, and evaluates the effectiveness of urban best management practices within the context of local stormwater management programs.

### THE EPA NATIONWIDE URBAN RUNOFF PROGRAM (NURP)

Most of the initial evidence concerning the water quality and habitat changes induced by urban stormwater runoff volumes and velocities emanated from state and regional water quality planning studies sponsored under Section 208 of the Clean Water Act. Although many 208 studies, including the Washington metropolitan area's 208 plan, established urban runoff as a water quality problem, significant uncertainty still existed as to its importance at a national level. Therefore, in 1978 the United States Environmental Protection Agency (EPA) initiated a five-year study to examine the significance of the nation's urban runoff problem. The study, termed the Nationwide Urban Runoff Program or NURP, was designed to build on the limited body of knowledge then available about the impacts of urban runoff on receiving water quality, and to develop practical engineering data on the relative cost and effectiveness of potential control measures. To accomplish this, EPA sponsored 28 separate urban runoff projects throughout the country. In 1979, the Washington, D.C. metropolitan region was selected as one of the NURP project sites.

### THE WASHINGTON NURP PROJECT

NURP research was conducted in the Washington region over a four year period (1979-1983). These studies were carried out by the Metropolitan Washington Council of Governments (COG) in association with the Northern Virginia Planning District Commission (NVPDC) and the Virginia Polytechnic Institute and State University (VPI). This report summarizes the principal findings and conclusions from that effort.

The general objectives of the Washington area NURP project were to examine the extent to which water quality control could be effectively integrated into existing Washington area stormwater management programs, and to determine what level of pollution benefits that this additional investment might achieve. Addressing these general questions involved investigation of five major research topics, including:

- Identifying the principal water quantity and water quality impacts of urban stormwater runoff within the Washington metropolitan area.



- Evaluating the pollutant removal capability of various urban best management practices (BMPs) currently in use within the region, and identifying BMP design features which have the greatest influence on pollutant removal capability.
- Developing a predictive methodology for estimating the costs of building and maintaining stormwater ponds so that the comparative costs of various kinds of stormwater ponds could be evaluated.
- Examining the importance of atmospheric deposition as a source of pollutants which can be eventually delivered in urban runoff, and to evaluate the effectiveness of source controls in reducing this supply.
- Developing and applying sophisticated watershed modeling tools to integrate NURP research into a coherent framework, so as to identify cost-effective runoff management strategies in developing watersheds.

The following discussion summarizes the principal findings and conclusions derived from each of these five major research areas.

## IMPACTS OF URBAN RUNOFF

### Water Quality Impacts

Although urban runoff is highly variable in nature, some indication of the average concentrations of typical substances found in Washington area stormwater runoff can be found in the table below. As can be seen, several constituents were detected at levels which can have adverse effects on receiving waters. For example, the high sediment concentrations frequently found in local runoff can cause excessive turbidity and sedimentation in urban streams. Similarly, observed concentrations of plant nutrients, such as nitrogen and phosphorus, are sufficient to stimulate algae growth, especially in impoundments or slow moving tidal waters. Bioassays conducted during the NURP study provided firm evidence that undiluted urban runoff can produce exceptionally high rates of algal productivity. Bacteria were frequently detected in urban runoff during storm events at levels which exceed public health criteria for water contact recreation. Local urban runoff also tends to contain high levels of oxygen demanding substances which have the potential to deplete dissolved oxygen levels in standing waters.

Trace metals, pesticides, and other toxic substances were occasionally detected in concentrations similar to those normally observed in untreated sewage or industrial effluents. Twenty-eight out of 128 toxic chemicals listed by EPA were discovered in 15 stormwater runoff samples analyzed in the Washington area. In general, most of the toxic substances detected were present in quantities which posed little or no environmental risk. Exceptions were the inorganic trace metals such as cadmium, copper, lead, nickel, selenium and zinc. Many of these metals did occasionally violate U.S. EPA criteria for protection of aquatic



# TYPICAL SUBSTANCES FOUND IN URBAN RUNOFF WASHINGTON, D.C. METROPOLITAN AREA

## Frequently Found in Urban Runoff (75% or greater frequency)

|                        | AVERAGE<br>CONCENTRATION | COMMENTS                                                                                       |
|------------------------|--------------------------|------------------------------------------------------------------------------------------------|
| Sediment               | 80 ppm                   | - Maximum levels up to 500-600 ppm, turbid water clarity                                       |
| Total Phosphorus       | 0.3 ppm                  | - both nutrients are present in sufficient quantity to highly stimulate algae growth.          |
| Total Nitrogen         | 2.1 ppm                  |                                                                                                |
| Chemical Oxygen Demand | 40 ppm                   | - Indicates relatively high organic content of urban runoff. Can deplete DO in standing waters |
| Bacteria               | 200 to 240,000 MPN/l     | - most fecal coliform measurements violate Public Health Standards                             |
| Zinc                   | 60 ppb                   | - Occasionally violates EPA source criteria for protection of aquatic life                     |
| Copper                 | 3 ppb                    |                                                                                                |
| Nickel                 | 30 ppb                   | - a product of fossil fuel combustion                                                          |
| Lead                   | 15 ppb                   | - has decreased by 50 to 75% since institution of lead controls on gasoline in early 1970's.   |

## Sometimes Found in Urban Runoff

### (25 to 75% frequency)

|                                                     |          |                                                                                                   |
|-----------------------------------------------------|----------|---------------------------------------------------------------------------------------------------|
| Arsenic                                             | 6 ppb    | - product of fossil fuel combustion                                                               |
| Antimony                                            | 3 ppb    | - element occurs naturally in soils                                                               |
| Beryllium                                           | 15 ppb   | - only rarely violated drinking water standards                                                   |
| Cadmium                                             | 1 ppb    | - approximately 15 to 25% of cadmium measurements violate acute freshwater aquatic life criteria. |
| Chromium                                            | 5 ppb    | - corrosion of automobile surfaces is a likely source.                                            |
| Mercury                                             | 0.2 ppb  | - only detected in 1/3 of all samples                                                             |
| Selenium                                            | 22 ppb   | - 47% violations of drinking water criteria.                                                      |
| Thallium                                            | 3 ppb    | - naturally occurring component of soils.                                                         |
| Pesticides<br>(Lindane, Heptachlor Epoxide, Aldrin) | <0.1 ppb | - commonly applied in gardens and homes to control insect pests in soil treatments.               |

## Rarely Found in Urban Runoff

### (less than 25% frequency)

|                            |          |                                                |
|----------------------------|----------|------------------------------------------------|
| Phenols                    | <10 ppb  | - often a component of exterior stains         |
| Ascerted Organic Compounds | <10 ppb  | - only 6 out of 113 organic compounds detected |
| DDT                        | <1.0 ppb | - only detected in one sample.                 |

\*Average of all urban/suburban land use sites monitored during the Washington NURP project.

Notes: ppm = parts per million (mg/l)  
ppb = parts per billion (ug/l)

ic life, human health or drinking water. However, the actual significance of these criteria violations is not well understood at the present time.

Extremely low levels of several pesticides (less than 0.1 parts per billion) were also detected in some samples. While suggesting an apparent link between residential insecticide application and contamination of urban runoff, the pesticide levels apparently posed no serious risks to either human health or aquatic life. In addition to the trace metals and pesticides, six organic compounds were found in one or more of the samples. None of these organic compounds were detected at levels considered toxic to either human or aquatic life.

### Physical Impacts

One of the most widespread and pervasive effects of urban runoff in developing areas is its impact on stream hydrology and morphology. As development proceeds, the percentage of watershed surfaces impervious to rainfall also increases. As a consequence, peak runoff volumes and velocities tend to increase while percolation to groundwater storage usually decreases. This, in turn, leads to wider variations of stream flow characterized by flash flooding at one extreme and lower dry weather flows at the other. This disturbance to the hydrologic regimes of streams can adversely affect aquatic habitats, so as to render them unsuitable for the support of many aquatic organisms present prior to urbanization. These changes are usually typified by:

- Physical disturbance of benthic and riparian habitat by sedimentation and streambank erosion.
- A more shifting, unstable and coarsely textured streambed.
- Changes in the diversity and abundance of aquatic insects upon which sensitive fish species forage.
- Wider and shallower stream channels with fewer pools and riffles which form excellent fish habitat.
- Disturbance of riparian vegetation caused by channel widening.
- Greater extremes in water temperature.

The physical manifestations of these impacts to streams are easily observed when urban streams in the Washington region are contrasted with streams having more rural character. The net effect of these physical changes in stream habitat is usually a reduction in the diversity of the aquatic community. Although these effects were not a major focus of the Washington NURP project, they were clearly evident in comparisons of historical fish diversity records and stream habitat changes developed under the Seneca and Piscataway Creek watershed planning studies.

## Impacts to Downstream Water Quality

Although the principal effects of urban runoff in the Washington region appear to be on local streams and reservoirs, downstream receiving waters such as the Potomac Estuary can be affected by urban runoff as well. The pulsing nature of runoff often allows for significant transport of much of the urban sediment and nutrient loadings to the Upper Estuary. Nutrient loadings from urban runoff can then contribute to eutrophication problems in these waters, particularly since the nutrients entrained in urban runoff are often much more readily available for algal uptake than nutrients associated with agricultural runoff. As the metropolitan region continues to grow, and area treatment plants continue to remove more and more of the nutrient load (especially phosphorus), urban runoff loadings could become an increasingly important influence on the quality of the Potomac estuary.

## POLLUTANT REMOVAL CAPABILITY OF URBAN BEST MANAGEMENT PRACTICES

Six kinds of stormwater management controls in use within the Washington metropolitan area were analyzed to determine their effectiveness in removing pollutants borne in urban runoff. These structures included conventional dry stormwater ponds, extended detention dry ponds, wet stormwater ponds, grassed swales, infiltration trenches and porous pavement. Inflow and/or outflow from 12 BMP sites was monitored with automated sampling equipment for intervals of 12 to 18 months, and several different estimates of pollutant removal efficiency were computed. The general conclusions concerning the pollutant removal effectiveness of these urban BMPs are outlined below. The comparative pollutant removal capability of the BMPs studied are also displayed in the accompanying figure.

### Effectiveness of Controls

- Conventional dry stormwater management ponds were not effective in removing the sediments, nutrients, trace metals, or oxygen demanding materials entrained in urban runoff. Stormwater passed through the structure too quickly to achieve significant removal by settling. In some cases, the dry ponds actually become a net source of pollutants due to scour and resuspension of the pond bed.
- Extending the detention time of stormwater within dry ponds appeared to be a promising technique for removing several common constituents such as sediments, trace metals, and organic nutrients. Removal of biologically available nutrient forms, however, was minimal and did not materially reduce downstream algae growth potential. This suggested that the extended detention technique will not be useful in areas where control of nutrients is a primary management concern.
- "Wet" ponds which maintain a permanent pool in addition to peak runoff storage capacity were determined to be an extremely effective

tive urban best management practice. Removal rates for sediment and trace metals were comparable to the high levels observed at the extended detention facility. Also, the biological processes occurring within the pond effectively removed a high portion of the readily available nutrient forms. Algal assay experiments suggested that wet ponds could reduce downstream algal growth potential by as much as 95 percent.

- No statistically significant improvement in either runoff quality or quantity could be demonstrated for grassed swale drainage systems when they were compared with traditional curb and gutter conveyance systems. The poor performance of the grassed swales appeared to be related to the rapid passage of stormwater through the swales and the absence of significant settling on biological processes.
- Although several methodological and siting constraints limited the usefulness of the infiltration control comparisons, it appeared that these controls tended to be moderately effective in removing sediments, trace metals and oxygen demanding materials, but were generally ineffective in removing soluble nutrient forms and oxygen demanding materials.
- The use of porous pavement proved to be a very effective urban best management practice with respect to both runoff quality and quantity. High removal rates from a porous commercial parking area. were noted for nearly all water quality parameters examined.

#### COMPARATIVE POLLUTANT REMOVAL CAPABILITY OF URBAN BMPs

|                                         | Sediment | Trace Metals | Oxygen Demand | Organic Nutrients | Inorganic Nutrients | Algal Growth Limitation |
|-----------------------------------------|----------|--------------|---------------|-------------------|---------------------|-------------------------|
| Dry Stormwater Ponds                    | ●        | ○            | ○             | ○                 | ○                   | ○                       |
| Extended Detention Dry Stormwater Ponds | ●        | ●            | ●             | ●                 | ○                   | ⊗                       |
| Wet Stormwater Ponds                    | ●        | ●            | ●             | ●                 | ●                   | ●                       |
| Grassed Roadside Swales                 | ○        | ○            | ○             | ○                 | ○                   | ○                       |
| Infiltration Pits and Trenches          | ●        | ●            | ●             | ○                 | ○                   | ○                       |
| Porous Pavement                         | ●        | ●            | ●             | ●                 | ●                   | ●                       |

KEY      ● greater than 50 % removal      ○ between 25 and 50 % removal      ○ less than 25 % removal      ⊗ no data



## Design Approaches for Improving the Effectiveness of Urban BMPs

During the course of the BMP effectiveness study, several design concepts emerged which appeared to have significant potential for enhancing the pollutant removal capability of stormwater structures. These concepts included:

- Increasing the detention time of stormwater in pond structures enabled significant removal of particulate pollutants. Both laboratory and field data suggested that 6 to 12 hours of detention was sufficient to achieve about two thirds of the maximum theoretical removal rate for most pollutants. Since removal rates beyond 12 hours occur only in small increments (and the cost of adding additional storage remains constant) the achievement of longer detention times may not be cost-effective.
- Pond scour, resuspension, and short-circuiting are all processes which can severely limit the pollutant removal capability of any pond BMP. Therefore, special attention in the design process, should be placed on preventive measures such as revegetation, bank stabilization, energy dissipation, channelization and pond configuration.
- Infiltration-type BMPs can be extremely effective if they are oriented toward achieving rapid and complete infiltration of stormwater and maximizing the contact time of stormwater within the soil profile. In this respect, infiltration systems should be designed to retain stormwater within the structure for durations exceeding those suggested for ponds. Design detention times of 24 to 48 hours are now being recommended by the State of Maryland for infiltration BMPs. Even greater pollutant removal performance can be realized if the stormwater is permanently routed into the groundwater pool.
- The multi-purpose character of wet ponds, when coupled with their high pollutant removal capability, makes them an attractive stormwater management control. In general, the pollutant removal efficiency (and presumably the aesthetic, recreational and landscape values, as well) will become greater as pond size increases. Also, the establishment of rooted aquatic vegetation around the periphery of the pond can accentuate pollutant removal as well as attract wildlife. Establishing rooted aquatic vegetation may also have the beneficial effect of diminishing the nutrient supply available to algae during the summer months, thus alleviating a persistent maintenance concern.

## COMPARATIVE COSTS OF STORMWATER POND STRUCTURES

A detailed series of local and nationwide cost surveys were undertaken during the NURP study to develop a practical, easily applied methodology for esti-



mating the costs of various stormwater management ponds presently in use in the Washington area. The underlying concept behind the analysis was to provide local decision-makers with a consistent and comprehensive means of evaluating alternative stormwater management investments. The methodology accounted for four basic components of the total cost of a stormwater pond:

- Base Construction Costs -- the direct costs to the contractor or implementing agency (exclusive of land costs) to construct a pond at the development site in accordance with typical stormwater management design criteria.
- Construction-Related Contingency Costs -- the costs associated with administration and oversight during the period of pond design and construction.
- Pond Operation and Maintenance (O&M) Costs -- the costs to maintain a safe, functioning pond over its useful life or some specified planning period. O&M costs would provide for routine inspections and preventive maintenance performed on a regular basis; non-routine maintenance (such as sediment removal) or repairs to ensure structural integrity; and some allowance for administration of the maintenance program.
- Debt Service -- the cost of long term financing of the initial stormwater investment, which involved the assignment of a discount rate to factor payments for pond construction and upkeep over a specified planning period.

Using this methodology, the total costs of three types of stormwater ponds were developed for: conventional dry ponds, extended detention dry ponds, and permanent pool wet ponds. Major findings of the analysis follow.

## Construction Costs of Stormwater Ponds

### Dry Stormwater Ponds

Regression analysis of unit cost data applied to 31 representative Washington area dry and wet ponds (ranging in size from 2,700 to 740,000 cubic feet of storage) revealed that a dry stormwater pond's computed volume of storage could be used for planning purposes to predict the pond's construction costs. The principal relationship can be expressed by the equation:

$$\text{Base Construction Cost} = 77.4 \times V_s^{0.51}$$

(1980 Dollars)

where  $V_s$  equals the volume of storage of the dry pond, up to the crest of the emergency spillway. The resulting pond cost estimate excludes allowance for the costs incurred in planning and designing the pond. Research conducted for this study suggests an additional 25 percent for this factor.

Dry pond cost estimates derived by this formula indicated that the cost per unit of storage generally decreased as the volume of the pond increased. For example, the construction cost of a hypothetical 20,000 cubic foot dry pond was approximately 60 cents per cubic foot, whereas a larger, 60,000 cubic foot pond was estimated to cost 35 cents per cubic foot. As expected, the cost data suggested that certain economies of scale could be achieved by constructing larger ponds serving a larger portion of the drainage area, as opposed to building several smaller ponds. The economies of scale became less distinct as ponds got very large (i.e., in excess of 1,000,000 cubic feet).

#### Extended Detention Ponds

Modification to design criteria of conventional peak-shaving dry detention ponds to achieve longer detention times and higher levels of pollutant removal were estimated to involve about a 10 to 12 percent increase in dry pond construction costs.

#### Wet Ponds

Cost comparisons between wet ponds and dry ponds indicated that wet ponds cost some 26 to 46 percent more than single purpose dry ponds, primarily because of the extra pond volume required for the permanent pool. However, several factors may weigh in favor of wet pond construction despite these additional costs. These included the exceptional pollutant removal characteristics of wet ponds, and instances where site topography can accommodate the additional pond volume without substantial additional excavation.

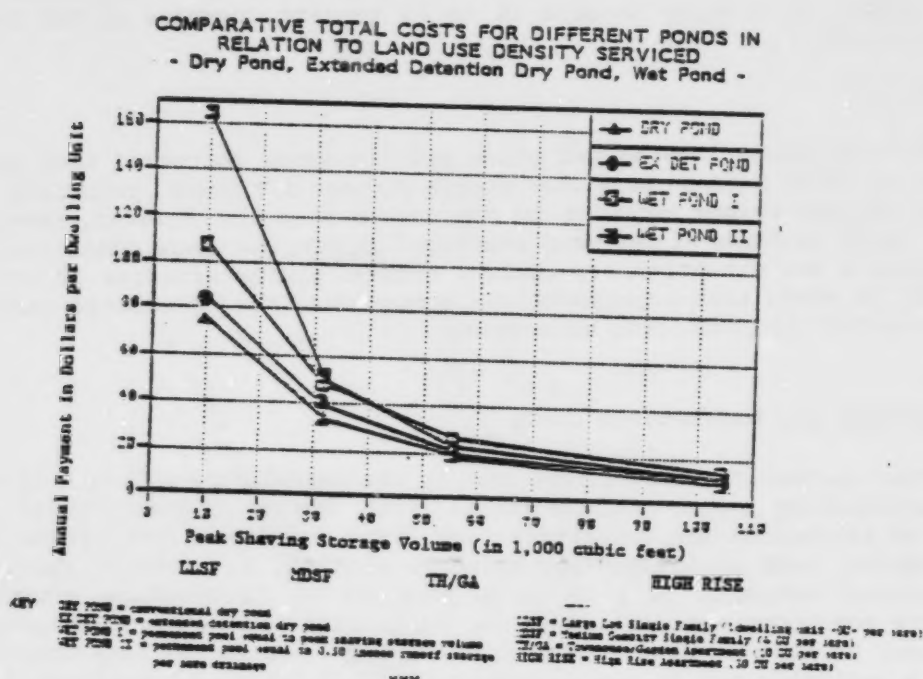
#### Pond Operation and Maintenance Costs

Another component of total pond cost is the expenditure involved in operating and maintaining a pond over its useful life. Typical O&M activities include a number of preventive and corrective tasks such as inspections, grass mowing, debris removal, bank stabilization, nuisance control, and removal and disposal of accumulated sediments on a 10 to 20-year cycle. Information assembled on maintenance practices experienced in the Washington region and elsewhere in the U.S. appears to support the practice of utilizing 5 percent of base construction costs as a realistic and fairly conservative "rule of thumb" estimate for projecting O&M costs for these structures. Wet ponds and extended detention dry ponds do not appear to require more maintenance than that assigned to conventional dry ponds. There is some indication that wet ponds that have considerable permanent pool volume may require less frequent sediment removal, which would reduce overall maintenance costs.

#### Total Annual Pond Costs

Total annual pond costs on a dwelling unit basis help portray the financial commitment associated with pond construction and upkeep over a typical 20-year planning period. Annual costs for conventional dry ponds serving a 20-acre development were estimated at about \$32 per dwelling unit (DU) at a medium density single family development, and at about \$16 per DU at a townhouse/garden apartment development. Estimated annual costs show a pattern of decreasing costs per unit of storage in instances where a larger pond is constructed to serve a larger drainage area. By way of comparison, the average annual Washington, D.C. area sewer bill in 1982 has been estimated at \$123 per household.

Although the annual payment for extended detention dry ponds and wet ponds is greater than that estimated for a conventional dry pond, the cost differences between pond types appears to be far less substantial (on a dwelling unit basis) when the ponds are employed to control runoff from higher density developments. The figure below compares the annual household costs of different ponds serving similar 20-acre residential developments. As shown, the cost differential between pond type is much less in the townhouse and high-rise development setting.



## ATMOSPHERIC DEPOSITION AND URBAN RUNOFF

Atmospheric monitoring efforts in the Washington area NURP project included operation of four wetfall/dryfall monitors and chemical analysis of Total Suspended Particulate (TSP) filter mats from eight regional high volume air samplers, and comparisons with observed pollutant loadings in urban runoff. The major conclusions of this field study were as follows:

- Average annual atmospheric deposition rates calculated at urban, suburban and rural areas suggested a general trend toward greater deposition rates from rural to suburban to urban sites for most parameters. This pattern was most pronounced for dryfall, but was also evident for wetfall deposition rates for some parameters.
- Wetfall was the most important deposition mechanism for total nitrogen, nitrate, organic nitrogen, COD, copper, and zinc. By way

of contrast, dryfall was relatively more important as a depositional mechanism for most soil related constituents, such as total solids, iron, lead, total phosphorus, and ortho-phosphorus.

- Atmospheric deposition rates did not vary significantly between the two suburban stations monitored, but were somewhat greater at the urban site located in Washington, D.C.
- In general, wetfall and dryfall rates were greatest in the spring, lowest in the summer, and intermediate in the fall and winter. Several factors were identified which might produce this seasonal pattern. They included pollen release, precipitation frequency, wind speed and direction.
- Significant differences in dryfall rates (but not wetfall) were noted at ground and roof top monitors at the Burke Village monitor. Ground level dryfall rates were approximately 25 to 40 percent higher for most parameters at ground level. Due to the proximity of motor vehicle traffic to the monitor, it is believed that either ground level emissions or re-entrainment of street dust were responsible for producing the higher ground level dryfall rates.
- Chemical analysis of TSP filters collected at eight regional high-volume air quality samplers revealed a striking uniformity in air mass concentration for total solids, phosphorus, lead, zinc, cadmium and manganese levels. No distinct regional patterns could be determined for nitrate, organic nitrogen, copper or iron, as air mass concentrations varied considerably among stations.
- Comparisons of atmospheric concentrations of pollutants between this study and a similar 1976 study suggested that while air mass concentrations of most pollutants had remained nearly constant between the summers of 1976 and 1980, the ambient air concentrations of lead had dropped nearly 60 percent. The institution of controls on leaded gasoline is believed to be primarily responsible for this decline. Almost proportional reductions in the load of lead in urban runoff were noted over the same period.
- pH measurements of rainfall in the Washington region showed a consistent pattern of acidity. Median pH values typically ranged between 4.0 and 4.1 units at all stations and during all seasons. The "acid rain" which occurs apparently does not influence the pH of surface waters, which is not surprising considering the well-buffered nature of local soils and rocks. Increased mobilization of trace metals from some urban surfaces caused by acid rain were noted at several monitoring sites. The regional impacts of acid rain on plants, soils, and materials is not known at present, and represents an important avenue of future research.



- Atmospheric loading represents a major source of the urban runoff load for several pollutants in highly urban areas. These include nitrogen, solids, zinc and lead. In the case of phosphorus and oxygen-demanding materials, other non-atmospheric sources appear to be more important in producing observed loads in urban runoff.
- The possibility of obtaining additional water quality benefits from the implementation of air emission control strategies is briefly discussed. One prominent example of such benefits includes the effective implementation of controls on lead emissions in recent years. This has been translated into nearly a proportional decrease in lead loadings in urban runoff.
- Ten major water quality parameters were evaluated through a three-stage process. This analysis suggested a reasonable potential for achieving positive water quality spin-off benefits through emission control for nitrate, cadmium and lead. Few, if any, spin-off benefits were likely to be achieved for the other parameters through emission controls.

## REGIONAL IMPLICATIONS OF WASHINGTON URBAN RUNOFF STUDY

Future development trends suggest that urban runoff will become an increasingly important factor affecting the quality of surface waters throughout the region. The best available estimates suggest that urban land development may increase by nearly 50 percent throughout the Washington metropolitan area between now and the turn of the century (MWCOC, 1979). Without effective runoff controls, local experience has shown that urbanization changes of this magnitude can be expected to induce undesirable changes in the quality and quantity of surface waters throughout many of the regions principal watersheds. Increased urbanization may have some adverse consequence on the beneficial uses of downstream receiving waters, particularly with respect to nutrient enrichment.

Over the past decade, local governments have increasingly recognized the need for urban stormwater controls. In most area jurisdictions, this had led to the adoption of stringent stormwater management policies and the encouragement of pre-development land use planning varies substantially among area jurisdictions, the regional commitment of resources to stormwater management has been extensive. Nearly 3,100 structures have been installed in the Washington area since the early 1970s. A recent regional survey indicated that nearly 200 stormwater structures were either approved or installed during 1982. Collectively, these controlled the runoff from an estimated 4.5 square miles of new urban and suburban development. The total area controlled by these structures represented 75 percent of all new residential and commercial development which took place during the year, based on best available estimates.

Most of the stormwater structures built in 1982 (over 75 percent) were conventional stormwater detention ponds, which function primarily to attenuate peak flows and reduce downstream bank erosion. There is a definite trend toward the design and installation of multi-purpose stormwater structures that provide water quality protection in addition to water quantity control. Approximately 20 percent of the stormwater structures built in 1982 were of this variety. The



trend toward multi-purpose structures represents a shift in direction in regional stormwater management away from exclusive control of water quantity towards more consideration of water quality protection. As the scope of regional stormwater management programs widens, more information on the effectiveness and costs of such an approach will be required.

#### PROTOTYPE NONPOINT SOURCE MANAGEMENT STUDIES: SENECA AND PISCATAWAY CREEK

Special water quality modeling studies were conducted in the developing Seneca and Piscataway Creek watersheds. These case studies applied the results of the Washington NURP research to ongoing local master planning efforts that were concerned with the water quality consequences of different land use/nonpoint source management options under consideration. Some of the more general conclusions from these studies have important regional implications for future directions in urban runoff management. These are discussed below:

- Uncontrolled urbanization is likely to have highly deleterious impacts on instream habitat and receiving water quality throughout the region. In particular, it is anticipated that uncontrolled stormwaters will produce increased rates of streambank erosion, elevate instream suspended sediment concentrations and lead to "flashy" streamflow regimes (typically characterized by increased peak discharges and reduced dry weather flows). The combined effect of these physical alterations of stream conditions can lead to the deterioration of aquatic habitat. With respect to impacts on receiving waters, the nutrient loadings associated with urban runoff have been shown to have a significant potential for inducing highly eutrophic conditions in standing waters. Contamination of runoff by trace metals and bacteria may also serve to limit beneficial uses of receiving waters as well.
- Both the water quality and quantity impacts of urban runoff can be effectively mitigated through the use of stormwater control structures with high pollutant removal capability. In both Seneca and Piscataway watersheds, the application of "wet" stormwater ponds was projected to result in overall water quality conditions which were equivalent or superior to levels currently experienced even after substantial conversion of undeveloped land to residential and commercial uses. By way of contrast, traditional "dry" stormwater management ponds exhibited little capacity to prevent future deterioration of instream habitat or receiving water quality. Thus, from the standpoint of efficiency, it would appear that existing stormwater management design criteria should be modified to allow for enhanced pollutant removal. Although only one such modification (wet ponds) was actually examined in the context of the watershed modeling efforts, previous NURP research has identified several other promising candidates (Chapter 2) such as extended detention or prolonged infiltration.

- The success of a water quality oriented stormwater management program is dependent on widespread application, full compliance and continuing maintenance. Model projections in each watershed provide strong evidence that a limited, poorly maintained, or otherwise incomplete application of controls will not be effective on a watershed-wide basis. Also, the importance of early planning on the part of local officials cannot be over-emphasized. Both watershed studies have shown that pre-development planning, in concert with watershed monitoring and modeling, can provide timely guidance on cost-effective means of controlling urban runoff before it becomes a major problem. As local experience has often suggested, urban runoff is much easier to manage before development begins, than after it has finished.
- Both the Seneca and Piscataway Creek watershed studies demonstrated that land use planning measures, while effective by themselves, cannot entirely eliminate the adverse effects of urban runoff. Planning measures which are oriented towards preserving agricultural and forest lands, and emphasize lower density development do have significant potential for mitigating stream impacts. However, the greatest overall level of watershed protection is realized when land use planning measures are combined with effective runoff controls.
- Control of the nutrient and sediment loadings from agricultural lands is a key element in any comprehensive nonpoint source control strategy in transitional urbanizing watersheds. Although agricultural activities may occupy a decreasing share of the total acreage, unit area cropland nonpoint loads can often be higher than urban or other substitute uses. Agricultural BMPs can be very effective in curtailing nonpoint loadings, and as the analysis in Seneca Creek has shown, are extremely cost-effective in comparison with structural urban BMPs.
- From the standpoint of comparative costs and benefits, both watershed studies provided strong evidence that water quality oriented urban BMPs, such as wet ponds, are a more attractive social investment than traditional "dry" stormwater management structures. For a modest increase in cost (approximately 20 to 50 percent), significant improvements in both water quality and quantity are realized when wet ponds are implemented. When fully applied to new development throughout a watershed, model projections indicate that wet ponds can reduce the impacts of urbanization to levels which approach existing conditions, and also provide substantial recreational, landscaping and aesthetic values. Model projections also suggest that when wet ponds and agricultural BMPs are applied in concert with land use planning measures (e.g., lower density zoning, and conservation of open space), the greatest overall improvements in both water quality and quantity conditions are likely to occur.

**CHAPTER ONE**  
**PROJECT OVERVIEW**

## CHAPTER I

### OVERVIEW OF THE WASHINGTON NURP PROJECT

#### INTRODUCTION

This Chapter summarizes the principal research objectives and monitoring arrangements of the Washington, D.C. Area Urban Runoff Project. The chapter begins with a description of the major elements and objectives of the study, followed by a brief outline of the roles of project participants. Background information on the environmental characteristics of the Washington metropolitan area is then presented, along with a synopsis of regional growth trends and current local directions in urban runoff control. Following this is a description of the nature and scope of the overall urban runoff monitoring program. A summary of the urban runoff data-base produced by this effort is provided in the next section. The chapter concludes with an outline of the contents and overall organization of subsequent chapters of the Final Report. Reference is also made to the availability of other supporting documents produced during the course of the Washington NURP project.

#### FOCUS OF STUDY

The Washington NURP project was directed to provide information on the overall effectiveness and costs of various types of structural best management practices (BMPs) for urban runoff control. The project involved extensive field monitoring of local BMP sites followed up by special analytical studies, applied laboratory research, and water quality model applications to evaluate the relative effectiveness of various types of locally used BMPs in removing sediments, nutrients, metals, and other substances of concern borne in urban runoff.

A principal objective of the project was to provide the data and analytical tools necessary to build water quality management objectives into ongoing jurisdictional programs which are now principally aimed at controlling localized flooding and other physical effects of urban stormwater. As such, the BMPs which were monitored were selected based upon evaluation of their applicability to environmental conditions in the Washington region and their adaptability to the institutional and regulatory aspects of ongoing local stormwater programs. Specific monitoring sites selected for these purposes were also designed to permit the concurrent measurement of runoff from different urban/suburban land use types generally representative of those found in developing portions of the metropolitan area. This was done to expand the region's current data base regarding land use/nonpoint loading relationships and ultimately to provide the analytical tools needed to permit a more precise understanding of urban runoff loading effects likely to accompany future regional growth.

Atmospheric wetfall and dryfall data and particulate data were also collected at different points in the metropolitan area to assess the significance of atmospheric sources as a component of loadings in urban runoff.



These data were statistically analyzed for potential variations in atmospheric loadings between different geographic areas which could materially affect the "transferability" of existing land use/nonpoint loading factors within the region, currently being used to evaluate potential urban runoff loadings.

Additionally, special research studies were conducted to 1) determine the presence of toxic substances in runoff, 2) evaluate urban runoff in terms of its capability to stimulate algal growth, 3) track the accumulation and movement of trace metals within the soils of BMPs, and 4), examine the settling dynamics of urban runoff.

Finally, the Washington project findings on BMP effectiveness and costs were applied in comprehensive case studies of two developing watersheds to evaluate nonpoint source management alternatives. In cooperation with local planning agencies, separate evaluations of future land use planning alternatives for the Seneca Creek and Piscataway Creek watersheds were conducted in terms of projected future water quality impacts with and without various levels of BMP controls. These studies both involved the use of calibrated water quality models and BMP cost data to identify the relative cost-effectiveness of different watershed nonpoint management strategies. The Seneca study also integrated considerations of the potential future impacts of agricultural land uses with and without accompanying agricultural BMP controls.

## PRINCIPAL PROJECT PARTICIPANTS AND THEIR ROLES

The Washington NURP project was conducted and managed by COG in association with the Northern Virginia Planning District Commission (NVPDC) and the Occoquan Watershed Monitoring Laboratory of the Virginia Polytechnic Institute and State University (VPI). VPI was responsible for all sample collection and lab analysis, with the exception of the priority pollutant scan analysis, which was conducted independently by JTC, Inc. VPI also conducted the special research studies on the relative bioavailability of nutrients in urban runoff, the settling behavior of pollutants captured in BMPs, and the accumulation and movement of captured trace metals as measured in the soil profiles of certain BMPs.

NVPDC performed extensive technical and statistical analysis of collected data to analyze urban runoff loadings for different land uses in the metropolitan area and to estimate pollutant removal efficiencies for certain urban BMPs. NVPDC also did a special analysis to relate observed NURP loading data to nonpoint loading information on "Central Business District" land uses collected under a previous local study (O'Brien and Gere, 1983). VPI and NVPDC both produced extensive final contract reports to COG on the results of their individual monitoring and analytical activities under the NURP project. These reports are available as separate reference documents to this Final Report.

COG conducted the principal analytical work on BMP costs and pollutant removal efficiencies, atmospheric loadings in urban runoff, and performed separate nonpoint source management studies for the Seneca and Piscataway watersheds. COG was also principally responsible for the analysis and presentation of data on overall project results in this Final Report.

## BACKGROUND DISCUSSION ON THE WASHINGTON NURP STUDY AREA

The Washington metropolitan region is an area of approximately 2,400 square miles, located within the Potomac River Basin and major portions of the Patuxent River Basin. Its principal urban areas are situated at the interface of the free-flowing Potomac River and the uppermost portions of the Potomac estuary. Free-flowing sections of the river provide about 60 percent of the region's drinking water, with one of the estuary's major tributaries, Occoquan Creek, supplying an additional thirteen percent.

The upper Potomac estuary and its tributaries constitute an important low salinity spawning area for anadromous fish of the Potomac and Chesapeake Bay. There are several hundred streams of varying flow in the region, tributary to both the free-flowing and estuary portions of the Potomac and Patuxent rivers. A large number of these streams are located in older residential or newly developing areas. Figure 1.1 shows the metropolitan region, its stream basins and some of its major jurisdictional boundaries.

A majority of the region falls within the piedmont and coastal plain geologic formations. The region's clay/sandy/silt loam soils, found on both formations, are considered severely erosion prone. The region is located in a temperate climatic zone, receiving an annual average precipitation of about 40 inches per year. Review of 30 years of rainfall data recorded at National Airport revealed an annual average of 112 rainfall events (MWCOG, 1979). High intensity, short duration events are usually associated with thunderstorms during the summer months, whereas low intensity, long duration events generally occur during the spring and fall months.

### Regional Development Trends

The Washington metropolitan area has a current (1980) population of approximately 3 million people, with 1.1 million households and 1.7 million employees. Year 2000 projections call for increases of 18 percent in population, 31 percent in households and 34 percent in regional employment. Using household projections as the best indicator of future land development trends, forecasted growth is expected to most significantly affect the region's established emerging suburban areas. The inner suburbs (Montgomery, Prince George's and Fairfax Counties) have forecasted a 36 percent increase in households by the year 2000. The outer suburbs (Loudoun, Prince William Counties) project a 108 percent increase in households, while the established central "core" areas of the Washington region (District of Columbia, Arlington County, City of Alexandria) forecast only an 8 percent increase.

To accommodate the area's expanding population, there will be a substantial conversion of rural lands to more impervious urban/suburban uses. Table 1.1 shows the current (1977) regional distribution of land use and projects general changes in land use patterns expected to eventually result from future regional growth. The table projects the conversion of approximately 162,000 acres or 253 square miles of land to more developed urban/suburban categories by the year 2000. This would represent about a 50 percent increase of urban/suburban land areas from the 1977 land inventory and a corresponding 14 percent decrease in rural land areas.

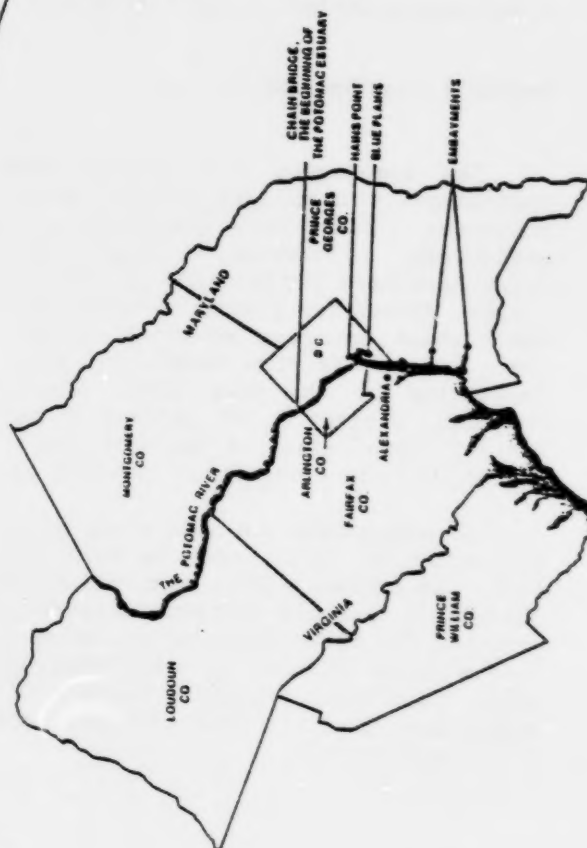
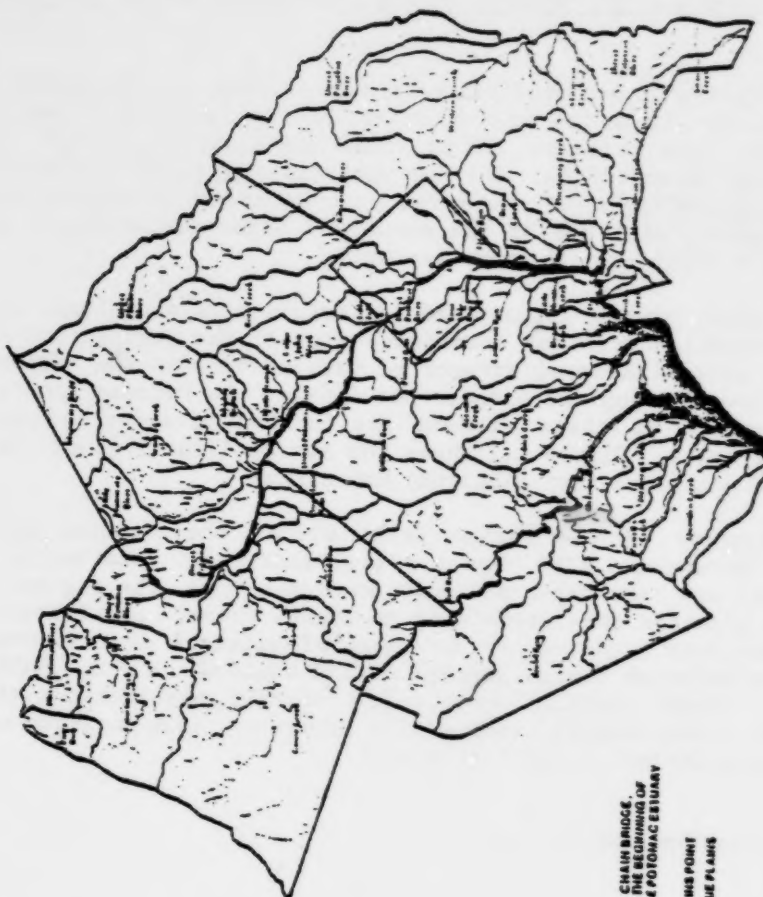


Table 1.1  
LAND COVER IN THE WASHINGTON METROPOLITAN AREA

|                              | ESTIMATED TOTAL<br>PERCENT<br>IMPERVIOUSNESS | EXISTING (1977)<br>LAND COVER IN<br>(1000's ACRES) | PROJECTED (2000)<br>LAND COVER IN<br>(1000's ACRES) |
|------------------------------|----------------------------------------------|----------------------------------------------------|-----------------------------------------------------|
| <u>Urban/Suburban Areas</u>  |                                              |                                                    |                                                     |
| Low-density single family    | 6                                            | 37                                                 | 101                                                 |
| Medium-density single family | 25                                           | 138                                                | 207                                                 |
| Townhouse/garden apartment   | 40                                           | 15                                                 | 18                                                  |
| Hi-Rise Residential          | 70                                           | 28                                                 | 31                                                  |
| Institutional                | 60                                           | 44                                                 | 48                                                  |
| Industrial                   | 70                                           | 15                                                 | 24                                                  |
| Suburban Commercial          | 90                                           | 40                                                 | 48                                                  |
| Central Business District    | 95                                           | 4                                                  | 6                                                   |
| Subt: Urban/Suburban Areas   |                                              | 321                                                | 483                                                 |
| <u>Rural Areas</u>           |                                              |                                                    |                                                     |
| Forest                       | T                                            | 513                                                | 437                                                 |
| Idle                         | 1                                            | 311                                                | 272                                                 |
| Cropland (Min. till)         | 1                                            | 62                                                 | 54                                                  |
| Cropland (Conv. till)        | 1                                            | 26                                                 | 23                                                  |
| Pasture                      | 1                                            | 207                                                | 185                                                 |
| Tended Areas                 | 1                                            | 67                                                 | 53                                                  |
| Subt: Rural Area             |                                              | 1186                                               | 1024                                                |
| Total Regional Acreage       |                                              | 1507                                               | 1507                                                |

SOURCE: Metropolitan Washington Council of Governments, Interim Report Washington D.C. Metropolitan Area Urban Runoff Demonstration Project, Sept., 1981, Vol. 1, p.25.



Table 1.2 provides a relative comparison of the average annual runoff generated from differing land uses and underlying soil types found in the Washington area. The table illustrates the substantial increases in runoff which are likely to occur as land is transformed from rural uses into more highly impervious urban and suburban categories. It suggests that the kinds of land use changes expected to accompany projected regional growth would result in substantial increases in annual runoff produced by current (1977) land uses in the absence of concurrent runoff controls. Peak stormwater volumes and velocities would also increase. And, as demonstrated by the research presented in this report, pollutant loadings from urban runoff would also be expected to increase substantially without accompanying urban BMP controls.

## REGIONAL DIRECTIONS IN RUNOFF CONTROL

### Local Stream Protection

The need for urban stormwater runoff control has become increasingly recognized as necessary for the mitigation of the impacts of urbanization on the volume of stormwater and its effect on local stream conditions. Most area jurisdictions now have some form of stormwater management regulation or control policy affecting new land development. Some local agencies also actively engage in predevelopment watershed land use planning measures to protect water quality.

The recent commitment of resources to stormwater management has been encouraging. Nearly 3,100 stormwater management structures have been installed in the Washington area since the early 1970's. A recent COG survey indicated that nearly 200 new stormwater structures were either approved or installed in the metropolitan area in 1982 (MWCOC, 1983). Collectively, the stormwater structures controlled the runoff from an estimated four and a half square miles of new urban and suburban development in 1982. The total area controlled by these structures represents about 75 percent of all new residential and commercial development which took place during that year.

Most of the stormwater structures built in 1982 continued to be conventional stormwater detention ponds, which function principally to attenuate peak flows and reduce localized downstream bank erosion. There appears to be an emerging trend, however, towards the design and installation of multipurpose stormwater structures that improve water quality protection. Approximately 20 percent of the stormwater structures built in 1982 provided some level of control to both runoff quantity and quality.

Table 1.2  
AVERAGE ANNUAL SURFACE RUNOFF SIMULATED  
FOR URBAN AND RURAL LAND USES BY SOIL TEXTURE

| LAND USE                     | PERCENT IMPERVIOUS | RUNOFF IN INCHES |                    |           |                    |            |                     | SANDY LOAM WITH PAN | SANDY LOAM | SANDY LOAM WITH PAN | LOAM | UNDIFFERENTIATED SOIL |
|------------------------------|--------------------|------------------|--------------------|-----------|--------------------|------------|---------------------|---------------------|------------|---------------------|------|-----------------------|
|                              |                    | CLAY LOAM        | CLAY LOAM WITH PAN | SILT LOAM | SILT LOAM WITH PAN | SANDY LOAM | SANDY LOAM WITH PAN |                     |            |                     |      |                       |
| ESTATE SINGLE FAMILY         | 3                  | 6.1              | 9.1                | 4.0       | 6.0                | 1.3        | 1.9                 |                     |            |                     | 3.6  |                       |
| LOW DENSITY SINGLE FAMILY    | 12                 | 9.2              | 11.8               | 7.2       | 9.0                | 4.4        | 5.0                 |                     |            |                     | 6.7  |                       |
| MEDIUM DENSITY SINGLE FAMILY | 25                 | 12.9             | 15.1               | 11.0      | 12.7               | 8.8        | 9.3                 |                     |            |                     | 10.7 |                       |
| TOWNHOUSE/GARDEN             | 45                 | 18.5             | 20.2               | 17.7      | 18.4               | 15.5       | 15.9                |                     |            |                     | 16.9 |                       |
| MID-RISE RESIDENTIAL         | 70                 | 25.8             | 27.0               | 25.3      | 25.7               | 24.0       | 24.2                |                     |            |                     | 24.8 |                       |
| INSTITUTIONAL                | 35                 | 15.7             | 17.2               | 15.7      | 15.5               | 12.2       | 12.6                |                     |            |                     | 13.8 |                       |
| FOREST                       | 1                  | 4.4              | 7.0                | 2.7       | 4.2                | 0.5        | 0.9                 |                     |            |                     | 2.3  |                       |
| IDLE                         | 1                  | 6.0              | 8.9                | 3.8       | 5.8                | 0.7        | 1.3                 |                     |            |                     | 3.2  |                       |
| MINIMUM TILLAGE              | 1                  | 6.6              | 9.4                | 4.1       | 6.2                | 0.8        | 1.5                 |                     |            |                     | 3.6  |                       |
| CONVENTIONAL TILLAGE         | 1                  | 6.9              | 9.8                | 4.4       | 6.6                | 0.9        | 1.6                 |                     |            |                     | 3.8  |                       |
| PASTURE                      | 1                  | 7.3              | 10.1               | 4.7       | 6.9                | 1.0        | 1.6                 |                     |            |                     | 4.1  |                       |
| FIELD GRASS                  | 7                  | 6.1              | 9.1                | 4.0       | 6.0                | 1.3        | 1.9                 |                     |            |                     | 3.6  |                       |
| INDUSTRIAL                   | 75                 |                  |                    |           |                    |            |                     |                     |            |                     |      | 28.0                  |
| SUBURBAN COMMERCIAL          | 90                 |                  |                    |           |                    |            |                     |                     |            |                     |      | 32.7                  |
| CBD                          | 95                 |                  |                    |           |                    |            |                     |                     |            |                     |      | 34.2                  |

NOTE: Surface Runoff was simulated with EPA's Nonpoint Source (NPS) Model using a continuous hourly rainfall record (NWS rainfall at National Airport) for calendar year 1967. Total rainfall for the year was 38.14 inches. Includes only surface runoff from pervious and impervious areas and does not include interflow and baseflow.

## Protection of Major Receiving Waters

Recognition of the downstream impacts of urbanization on the water quality of major regional receiving waters has prompted area local jurisdictions to look at stormwater management in a more comprehensive way. Specifically, these jurisdictions now perceive control of water quality, in addition to water quantity, to be an important aspect of urban stormwater management. Some examples of this trend are cited below:

- Concerns about future water quality in the Occoquan reservoir, which constitutes an important water supply for Northern Virginia residents, were instrumental in recent actions by Fairfax and Prince William Counties to require the installation of water quality-oriented urban BMPs to all new development in those portions of each county which drain to the Occoquan reservoir. Fairfax County has also rezoned some of the Occoquan drainage area to less intense urban uses, so as to provide an additional measure of water quality protection (This latter action is currently under litigation).
- In the State of Maryland, new stormwater management regulations have been adopted which require consideration of water quality protection as a component of local stormwater management programs. The regulations set forth a system of management priorities, which emphasize the use of infiltration and retention, over traditional short term detention storage techniques, in order to enhance runoff quality.
- Results of the seven-year EPA Chesapeake Bay Program have directly implicated nonpoint loads from agricultural, and to a lesser extent, urban sources as being partly responsible for some of the ecological disturbances observed in the main Bay channel as well as in the estuarine portions of the Potomac and Patuxent Rivers (US EPA, 1983). Out of concern for such influences, targets for the reduction of total nonpoint loadings have recently been set for the Patuxent River Basin (Md OEP, 1983) and recommendations have been made for the implementation of urban and agricultural BMP's throughout the Chesapeake Bay Basin (US EPA, 1983).

Because water quality protection has become an increasingly recognized component of local stormwater management programs, research conducted in the Washington NURP project has been aimed at enhancing the current body of knowledge on this emerging subject.

## SUMMARY OF THE NURP MONITORING PROGRAM

Figure 1.2 illustrates the location of the BMP, atmospheric, and stream monitoring stations operated under the Washington NURP project. As can be seen, the sampling effort was geographically dispersed throughout the region in the attempt to represent the range of conditions affecting urban runoff insofar as possible within the limits of the overall project. Table 1.3 summarizes the actual lab measurements conducted for each type of sample collected. The sections below describe the nature of the various runoff and atmospheric monitoring activities which were undertaken.

Figure 1.2  
LOCATION OF NURP MONITORING SITES

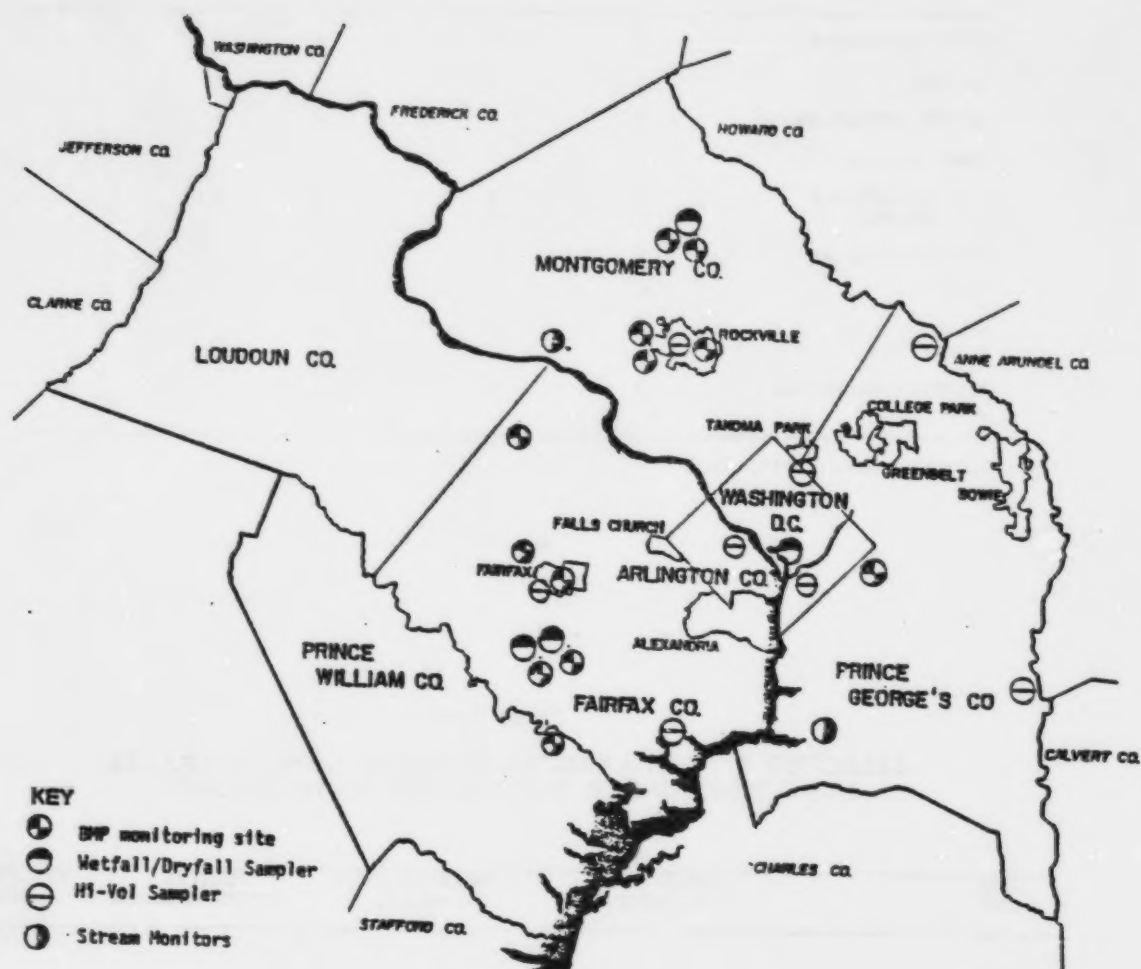




Table 1.3  
WATER QUALITY MEASUREMENTS  
WASHINGTON NURP PROJECT

| MEASUREMENT                  | RUNOFF | STREAM<br>BASEFLOW | ATMOSPHERIC<br>WETFALL/DRYFALL/HI-VOL. |   |   |
|------------------------------|--------|--------------------|----------------------------------------|---|---|
| PLANT NUTRIENTS              | X      | X                  | X                                      | X | X |
| SOLIDS                       | X      | X                  |                                        | X |   |
| OXYGEN DEMANDING             | X      | X                  | X                                      | X |   |
| HEAVY METALS                 |        |                    |                                        |   |   |
| - EXTRACTABLE                | X      | X                  | X                                      | X | X |
| - SOLUBLE                    | X      | X                  | X                                      | X | X |
| BACTERIOLOGICAL              | X      | X                  |                                        |   |   |
| FLOW                         | X      | X                  |                                        |   |   |
| OTHER PHYSICAL<br>PARAMETERS | X      | X                  | X                                      |   |   |
| PRIORITY POLLUTANT<br>SCAN   | X      | X                  |                                        |   |   |

SOURCE: OWML (VPI), 1983

Table 1.4  
SELECTED SITE CHARACTERISTICS OF LAND SURFACES  
MONITORED UNDER WASHINGTON NURP PROJECT

| LAND<br>USE                                  | DENSITY<br>(D.U./ACRE) | DRAINAGE AREA<br>(ACRES) | PERCENT<br>IMPERVIOUSNESS | PERCENT<br>SLOPE |
|----------------------------------------------|------------------------|--------------------------|---------------------------|------------------|
| Low Density<br>Single Family<br>(3 Sites)    | 1.2-2.2                | 9-48                     | 19-24                     | 2-9              |
| Medium Density<br>Single Family<br>(2 Sites) | 2-8-3.0                | 19-27                    | 34                        | 4-5              |
| Townhouse/<br>Garden Apt.<br>(3 Sites)       | 6.1-16.0               | 2-88                     | 30-55                     | 4-8              |
| Office (1 Site)                              | --                     | 4                        | 70                        | 3                |
| Industrial (1 Site)                          | --                     | 20                       | 79                        | --               |
| Shopping Center<br>(1 Site)                  | --                     | 5-55                     | 79-90                     | 2                |

## BMP Pollutant Removal Effectiveness Monitoring

The pollutant removal capability was evaluated based on field monitoring data collected on runoff entering and/or leaving the following twelve control sites:

- Stormwater management ponds -(6 sites) including:
  - 3 "wet" ponds having permanent pools
  - 2 "dry" ponds
  - 1 "extended detention" dry pond
- Grassed swale drainage systems (3 sites)
- Runoff infiltration trenches (2 sites)
- Porous asphalt parking lot (1 site)

Field monitoring involved the activation of automated flow and runoff sampling equipment whenever sufficient runoff was produced to permit measurement. For the stormwater management ponds, sampling stations were installed at pond inflow and outflow points and BMP pollutant removal efficiencies were calculated via comparisons of flow-weighted inflow and outflow loadings. For the grassed swales, infiltration trench, and porous pavement structures, the diffuse nature of runoff entering the sites did not permit direct measurement of inflows. BMP efficiencies for these sites were therefore calculated by sampling runoff outflows and comparing outflow loading data to runoff loadings monitored at other sites of similar land uses in the region which had comparable rainfall records and no BMP controls. To ensure comparability of rainfall/runoff data, raingage installations were also installed at or near each BMP site.

Monitored BMP sites were selected which drained small watersheds having homogeneous urban land uses. The eleven watersheds monitored under NURP covered a range of uses, densities, drainage areas, degrees of imperviousness and slope conditions representative of those found throughout the Washington area. Characteristics of these watersheds are shown in Table 1.4.

## Atmospheric Source Monitoring

Atmospheric influences on urban runoff loadings were monitored at five sites in the metropolitan area using "wetfall/dryfall" sampling equipment. These monitors allowed for the automated collection and segregation of constituent loadings which fell out of the atmosphere during dry weather from those washed out during rainfall. During intervals of dry weather, a dryfall collection bucket was exposed to the atmosphere while a "roof" covered the wetfall sampler. When rainfall occurred a sensor would slide the movable roof off the wetfall bucket and onto the dryfall bucket, thus permitting the isolation of loadings from these components of the total atmospheric source load. In addition to providing data needed for the quantification of

atmospheric loadings, the wetfall samples were also analyzed for pH to determine potential "acid rain" effects on area waters. As a supplement to the wetfall/dryfall sampling program, total suspended particulate (TSP) filter mats were collected from eight high-volume air samplers scattered throughout the region. These were analyzed to help determine if there were substantial variations in regional air quality which could cause atmospheric influences to materially affect urban runoff land use loading rates between jurisdictions.

### Stream Sampling

In addition to the BMP and Atmospheric Monitoring sites, separate stream monitoring stations were established on Seneca Creek and Piscataway Creek. These stations were also automated to permit the collection of composited stream samples during periods of storm runoff. Both stations also had stream flow gages on site and both were supported by raingages strategically located within the watershed. Data collected through the automated stations were further augmented by a weekly base stream flow grab sampling program.

### Other Monitoring Work

Other sampling activity included the collection of one storm sample at each of the 15 BMP monitoring sites to scan for the possible presence of 128 toxic substances specified in EPA's priority pollutant list. Also, the six urban runoff monitoring sites which were served by grassed roadside swale or detention basin BMPs were periodically sampled for trace metal levels in underlying soils. Emphasis was placed on determining the movement of metals through the BMP and underlying soils.

### BMP COST EVALUATIONS

In conjunction with the BMP monitoring study, a detailed local survey was conducted to develop unit cost data on stormwater management pond construction and maintenance based on local experience of public works agencies, engineering consultants and construction firms. This survey was augmented by an extensive literature search and selective survey of agencies throughout the U.S. and Canada. Based on this work, formulas were developed for establishing the total and annualized construction and maintenance costs involved in meeting stormwater management requirements. Developed cost information included:

- construction cost/volume of storage relationships
- annual pond maintenance costs (as a percent of construction costs)
- costs per household (by density)
- costs for commercial/industrial land uses (by acre)

The cost survey was developed in cooperation with the National Association of Home Builders, Northern Virginia Builders Association, and the Suburban Maryland Home Builders. In conjunction with the data on BMP effectiveness, it is believed that the data on stormwater management cost will be of significant

utility to area jurisdictions and the business community as they evaluate future directions in urban runoff control from their various regulatory, program management, and cost/benefit perspectives.

## DATA BASE SUMMARY

The final data base developed under NURP was substantial, especially when considered in combination with results of previous runoff monitoring conducted for COG (1976-77) in support of the WRPB's regional "208" Water Quality Management Plan (MWCOCG, 1978). As shown in Table 1.5 the composite NURP and "208" monitoring programs produced urban runoff loading information from 26 separate sites covering five broad land use categories ranging from large lot single family residential through high density apartments and commercial/industrial uses.

Table 1.5  
COVERAGE OF WASHINGTON NURP AND 208 MONITORING  
DATA BY LAND USE

| LAND USE                   | NURP<br>(1980-81)<br>(Sites in entire WMA) | 208<br>(1976-77)<br>N. Va. Sites | TOTAL |
|----------------------------|--------------------------------------------|----------------------------------|-------|
| LARGE LOT SINGLE FAMILY    | 3                                          | 2                                | 5     |
| MED. DENSITY SINGLE FAMILY | 2                                          | 3                                | 5     |
| TOWNHOUSE/GARDEN APT.      | 3                                          | 4                                | 7     |
| COMM./IND.                 | 3                                          | 3                                | 6     |
| HIGH RISE RES.             | -                                          | 3                                | 3     |
|                            | 11                                         | 15                               | 26*   |

\*Central Business District NPS Loading Information was also developed through separate sampling information provided from the District of Columbia Combined Sewer Overflow Study (O'Brien and Gere, 1983).

As noted earlier, the NURP work also produced pollutant removal data collected at 18 monitoring stations covering six different urban BMP types thought to have the best potential for extensive application in the region. In all, runoff from over 750 stations/storms was monitored under NURP (602 station/storms) and the earlier 208 work (154 station/storms). Well over 6000 lab analyses were conducted on urban runoff from these storms for the parameters described previously on Table 1.3. Because of the flow-composite sample collection techniques which were used, the samples which received lab analysis actually represented tens of thousands of individual runoff samples collected in the field to represent the full range of each runoff hydrograph.

Additionally, nearly 400 wetfall and dryfall samples were analyzed from four monitoring stations and monthly particulate samples were evaluated from eight high volume atmospheric samplers over a 22 month period.



In summary, the Washington NURP project produced one of the largest data bases assembled from the 23 separate NURP projects sponsored nationally by EPA. In combination with the earlier work on runoff done in support of the areawide 208 plan, the data base on urban runoff loadings, BMP efficiencies and BMP costs is believed to be one of the most complete and sophisticated available in the country today.

## ORGANIZATION OF THIS REPORT

The Final Report is organized as follows. Overall project findings are summarized in the Executive Summary preceding this Chapter. Chapter II describes the monitoring program, data analysis, and results of BMP pollutant removal capability study. At the end of Chapter II and all succeeding chapters, conclusions on principal research findings are presented.

Chapter III provides the results of the analysis undertaken on the costs of BMP pond-type runoff controls. Chapter IV presents the analysis of atmospheric loadings as they affect urban runoff quality in the Washington region.

Chapter V describes findings from a series of special monitoring, laboratory and analytical studies undertaken to further characterize urban runoff loadings and the principal physical and chemical processes which help determine BMP efficiencies. Finally, Chapter VI presents case study applications of NURP project results to two developing Washington area watersheds. This work involved comprehensive water quality modeling applications that evaluate the relative cost-effectiveness of various land use and nonpoint management options under consideration for water quality and local stream protection.

## Supporting Documentation

In addition to this Final Report, a total of 16 separate project reports were prepared which further detail the technical basis of findings on each of the specific research tasks conducted under the Washington NURP study. A listing of these individual reports is presented in Table 1.6. The reader is encouraged to obtain copies of these reports from the Metropolitan Washington Council of Governments if their interest in a particular subject area goes beyond the summary presentation of results found in this document. For a broader national perspective on urban runoff problems, as distilled from EPA's review of composite data collected from 28 individual NURP projects, the reader is encouraged to contact the EPA Water Planning Division (Washington, D.C. 20460) for a copy of EPA's final report on the agency's Nationwide Urban Runoff Program.

Table 1.6

# TECHNICAL REPORTS ISSUED ON ASPECTS OF THE WASHINGTON AREA NATIONWIDE URBAN RUNOFF PROJECT

| Title |                                                                                                                   | Date            | Authors            |
|-------|-------------------------------------------------------------------------------------------------------------------|-----------------|--------------------|
| 1.    | Final Contract Report on the Washington NURP Project                                                              | May, 1983       | GMH                |
| 2.    | Final Contract Report on the Washington NURP Project                                                              | April, 1983     | IVP/PC             |
| 3.    | Final Contract Report on Priority Pollutant Analysis                                                              | September, 1982 | JIC and Associates |
| 4.    | Pollutant Removal Capability of Urban Best Management Practices                                                   | September, 1983 | HACOG/DEP          |
| 5.    | An Evaluation of the Costs of Stormwater Management Pond Construction and Maintenance                             | March, 1983     | HACOG/DEP          |
| 6.    | Final Report on the Seneca Creek Watershed Management Study Vol. I and II                                         | October, 1983   | HACOG/DEP          |
| 7.    | Final Report on the Piscataway Creek Watershed Management Study                                                   | August, 1983    | HACOG/DEP          |
| 8.    | Water Quality in Seneca Creek: A Technical Assessment                                                             | August, 1982    | HACOG/DEP          |
| 9.    | Water Quality in Piscataway Creek: A Technical Assessment                                                         | April, 1983     | HACOG/DEP          |
| 10.   | The Seneca Creek Watershed Model: Documentation of the Hydrologic Calibration and Verification                    | April, 1982     | HACOG/DEP          |
| 11.   | The Piscataway Creek Watershed Model: Documentation of the Hydrologic Calibration and Verification                | May, 1982       | HACOG/DEP          |
| 12.   | The Seneca Creek Watershed Model: Documentation of the Water Quality Calibration                                  | May, 1983       | HACOG/DEP          |
| 13.   | The Piscataway Creek Watershed Model: Documentation of the Water Quality Calibration                              | May, 1983       | HACOG/DEP          |
| 14.   | Management of Stormwater and Water Quality in an Urbanizing Watershed                                             | July, 1983      | HACOG/DEP          |
| 15.   | Interim Report on the Washington NURP Project, Volume I and II                                                    | September, 1981 | HACOG/DEP          |
| 16.   | Comparison of Nonpoint Loadings from Suburban and Downtown Central Business Districts (contained in Reference 15) | September, 1981 | IVP/PC             |

Publications may be ordered through the CCG Metropolitan Information Center,  
1675 Eye Street, N.W., Washington, D.C. 20006. Phone number (202) 223-6800, ext. 230

## REFERENCES

- Maryland Office of Environmental Programs (Md. OEP). Revised November, 1983. 208 Water Quality Management Plan for the Patuxent River Basin.
- Metropolitan Washington Council of Governments (MCOG), June 1978. Metropolitan Washington Water Quality Management Plan. Prepared for the Metropolitan Washington Water Resources Planning Board.
- 
- Metropolitan Washington Urban Runoff Demonstration Project, Grant Application. Prepared for Metropolitan Washington Water Resources Planning Board. 216pp. —, May 1979.
- 
- Metropolitan Washington Water Quality Management Plan: Plan Supplement. Prepared for Metropolitan Washington Water Resources Planning Board. —, December 1980.
- 
- River Water Quality 1982: Conditions and Trends in Metropolitan Washington, prepared for Water Resources Planning Board. 112pp. —, August 1983.
- 
- Northern Virginia Planning District Commission (NVDC). April 1980. Guidebook for Screening Urban Nonpoint Pollution Management Strategies. Prepared for Metropolitan Washington Council of Governments. 160pp.
- 
- U.S. Environmental Protection Agency (EPA) Region I. September 1983. Chesapeake Bay: A Framework for Action. 186pp.

**CHAPTER TWO**  
**POLLUTANT REMOVAL**  
**CAPABILITY OF URBAN**  
**BEST MANAGEMENT PRACTICES**



## CHAPTER II

### POLLUTANT REMOVAL CAPABILITIES OF URBAN BEST MANAGEMENT PRACTICES (BMPs)

#### INTRODUCTION

A major component of the Washington area NURP project was an extensive field investigation of the comparative pollutant removal capability of six urban best management practices (BMPs) in suburban Maryland and Virginia. This chapter details the major findings of this effort and is organized in the following manner. The first section provides a general description of each BMP, and also describes the individual characteristics of each monitoring site. In the second section, the various methods which were used to monitor BMPs and compute their efficiency are discussed. In the third section, each of the urban BMPs are evaluated in terms of their overall pollutant removal performance. Finally, in the last section, the major factors which appeared to influence the effectiveness of each monitored BMP are identified. Based upon this analysis, general design principles that maximize pollutant removal are proposed for each BMP type evaluated.

#### Urban Best Management Practices Analyzed

Most of the urban BMPs investigated in this study were designed and have been applied to control peak discharges of urban stormwater runoff in accordance with local stormwater management criteria. The study was centered on the collection of field measurements. The degree of pollutant removal achieved by these practices and suggested design criteria that would optimize peak runoff volume control and maximize pollutant removal were based on the observed performance of these controls. It was felt that an urban BMP program oriented toward existing stormwater management regulations and institutions would have the best potential for implementation in the Washington metropolitan area.

#### BMP Site Selection

The site selection process for evaluating the pollutant removal potential of urban BMP's was extensive. Local stormwater technicians from a special Water Resources Planning Board Committee identified and evaluated hundreds of structures in the region as candidates for monitoring under the Washington NURP project. Candidate sites were ranked according to a common set of criteria identified in Table 2.1. The final set of sites that were evaluated were selected from this list. Complete details of the site selection process can be found in an earlier NURP project report (MWCOC, 1980). A brief discussion of each BMP type evaluated along with the specific monitoring site(s) is presented below:

## "Dry" Stormwater Management Ponds

"Dry" stormwater detention ponds are typically designed to temporarily store runoff to attenuate, or "shave", peak runoff rates from developed areas. Such structures have been the single most common stormwater control applied within the Washington area. Over 2000 have been constructed in area jurisdictions since the early 1970's (MWCOCG, 1983b). Normally empty during dry weather, these basins rapidly fill up during large storm events. The release rate of water from the basin is controlled by the size of the outlet pipe or control device that drains the pond. Typically, such structures are designed to detain stormwater for one to two hours. The dry pond investigated in the course of this study was located in the Lakeridge subdivision in Prince William County, Virginia. Essential characteristics of the pond are detailed in Table 2.2

## Extended Detention Dry Ponds

A major question evaluated under the NURP study was the extent to which the runoff detention time in conventional dry stormwater ponds could be modified to enhance their pollutant removal capabilities. Based upon previous local investigations sponsored by the WRPB (NVPDC, 1980), it was thought that modifications to traditional dry pond design which extend detention times would provide time for increased settling and removal of pollutants entrained in urban runoff. To test this hypothesis, a conventional dry pond at the Stedwick site in Montgomery Village, Md. was modified to achieve greater detention times. The original outflow pipe was modified by adding a perforated riser enclosed in a gravel jacket that controlled pond release and drawdown. As a result, stormwater runoff was detained for 6 to 8 hours, instead of the typical one to two hours. It should be noted that the original design of the pond modification called for detention times of up to 24 hours. Unfortunately, the pond outlet modification apparently leaked and never achieved detention times exceeding 8 hours. Principle features of this facility can be found in Table 2.3.

## "Wet" Ponds

Stormwater retention or "wet ponds" represent a small but growing segment of local stormwater structures. In addition to providing temporary storage for peak runoff volumes as in dry ponds, these structures also have additional storage and outlet devices which maintain a permanent pool of water throughout the year. As such, they serve as a multipurpose landscape feature for the developer, providing aesthetic, recreational and wildlife attraction benefits.

An important hypothesis investigated under the Washington NURP project was that wet ponds also had significant potential to be quite effective in removing pollutants borne in urban runoff. The major reason for this assessment was that several different pollutant removal mechanisms were believed to operate in these ponds, including physical settling, chemical flocculation and transformation, and biological uptake. The three wet ponds which were monitored were Burke, Westleigh and Fair Oaks. Their principal characteristics are detailed in Tables 2.4-2.6.

### Grassed Roadside Swales

Another promising urban best management practice evaluated was the replacement of conventional roadside curb and gutter conveyance systems with grassed swales. Such practices had been applied in suburban areas of Washington as stormwater management structures designed to reduce peak runoff volumes through reduced impervious area and infiltration into the soil profile. Swale drainage systems have usually been applied to control runoff from low density residential areas.

The removal of pollutants in runoff via swales was hypothesized to occur in several ways. First, the grassed swale drainage area would be expected to accumulate airborne and vehicular pollutants at lower rates than commonly experienced with impervious curb and gutter systems because of their smaller degree of impervious cover. Secondly, as stormwaters passed through the grassed swales, it was thought that the vegetation would act as a natural filter, removing pollutants and allowing the runoff to infiltrate into the soil profile where additional pollutant removal might be accomplished. In the NURP study, the quantity and quality of runoff from these grassed swale sites was compared to observed runoff from similar sites utilizing conventional curb and gutter collection systems. The swale sites monitored were at Dufief, Fair Ridge and Stratton Woods. The general features of these sites are elaborated on in Tables 2.7 through 2.9.

### Infiltration Controls

Another emerging concept in Washington area urban stormwater management has been the application of soil infiltration control structures as a means of achieving stormwater management effectiveness. Infiltration controls collect and route runoff into devices which allow for gradual infiltration of the stormwater into the soil profile or through a coarse gravel filter. This serves to provide temporary storage for the stormwater, where pollutant removal can occur by various physical, chemical and biological means. An additional pollutant removal mechanism was assumed to be direct reduction in flow volumes, since some portion of the flow would be permanently directed into the soil profile.

In the NURP study, two infiltration design concepts were investigated. The first involved the use of an infiltration trench in a small community shopping center at Burke Village in Fairfax, Virginia (Table 2.10). This structure was located adjacent to the center's parking lot, and consisted of a shallow trench backfilled with coarse gravel. The trench was connected with storm drainage system via an outlet pipe at the end of the trench. The total storage associated with the structure was slightly over 11,000 cubic feet, which represents about 1/2 to 1/3 of the volume of runoff expected from the tributary shopping center during the two-year design storm.

The second infiltration device, the Dandridge infiltration pit, was designed to divert runoff from a townhouse development into a gravel pit, which was drained by a series of underground perforated tile drains. The void space within the structure, slightly over 4000 cubic feet, was approximately one half of the storage required to control runoff from the two-year design storm (Table 2.11).

## Porous Pavement

Another urban best management practice which has gained popularity in recent years is the utilization of porous pavement in lieu of normal asphalt in parking lots. These structures are similar in many respects to infiltration controls in that they divert a significant portion of the stormwater runoff volume into the soil profile. In the porous pavement site monitored in the Washington area NURP project (Rockville City Center Parking Lot - Table 2.12), the stormwater from a 2.2 acre conventional pavement area was conveyed over 2.0 acres of "popcorn" porous pavement. The porous pavement was underlain by a bed of coarse gravel, and drained by a series of perforated tiles that conveyed some of the stormwater to the outlet area. The rapid infiltration of the stormwater through the many pores of the pavement, the subsequent absorption of pollutants to soil particles, and the general downward movement of water to the groundwater pool were hypothesized to control stormwater and effectively remove a wide variety of pollutants.

Table 2.1  
SITE SELECTION CRITERIA FOR URBAN BMP MONITORING

1. **Tributary Land Use** - BMP sites draining homogeneous land uses were preferred. These land uses had to be typical of those found throughout the Washington metropolitan area. The aggregate of all sites selected should cover the range of land use/site imperviousness/site activity characteristics typically found in the region. Sites having drainage with existing or planned construction activity during the monitoring period were not considered.
2. **Size of Drainage Area** - Sites were preferred which had drainage areas of up to 40 acres for typical "on-site" stormwater management facilities; or which ranged from 50-150 acres for larger "off-site" structures controlling more than one major development.
3. **Soil Types** - Sites were selected to cover the range of predominant soil types and soil hydrologic groupings typically found in the metropolitan area.
4. **Volume of Storage** - Sites were preferred which met or exceeded local jurisdictional stormwater management requirements usually aimed at providing pre-development peak runoff control levels for the two year and/or ten year frequency storm.
5. **Structural Inlets/Outlets** - To minimize equipment installation costs, sampling costs, and data analysis, sites were preferred which had one inlet and/or outlet and a minimum of direct overland flow drainage.
6. **Slopes** - Sites having moderate slopes of 2-7 percent were preferred.
7. **Geographical Coverage** - Sites were selected with the objective of achieving maximum regional coverage in order to provide data which could help determine the transferability of nonpoint loading rates for typical land uses between jurisdictions. Sites were also preferred which were located in watersheds which had been rated as "critical" by the Metropolitan Washington Water Resources Planning Board because of existing or forecasted nonpoint loading problems.
8. **Monitoring Station Access and Security** - Sites which had good regional access under all weather conditions were preferred. Because the laboratory for sample analysis was located outside of the region's central area, it was important for sites to be reasonably proximate to major interjurisdictional transportation routes such as the Washington beltway I-495, I-95, I-270, and I-66. This minimized the time required for sample collection following storm events. Considerations as to overall station security and the susceptibility of monitoring equipment to potential vandalism were also important in site selection.



Table 2.2

## BMP FACT SHEET: LAKE RIDGE DRY STORMWATER POND

## GENERAL FEATURES

**FACILITY NAME:** LAKE RIDGE  
**TYPE OF BMP:** Conventional Stormwater Detention Basin (DRY POND)  
**LOCATION:** Thousand Oaks subdivision in Prince William, Virginia

**OPERATION:** Empty basin fills up with runoff during a storm event, release of water is governed by the size of the outflow pipe, and the height of the riser. Detention within the pond is typically 1-2 hours. Pond was a converted sediment trapping basin.

## POLLUTANT REMOVAL MECHANISM(S)

Reliance on physical settling alone and minimum infiltration into the pond bed which occurred during brief peak flow residence times (1-2 hours)

## WATERSHED CHARACTERISTICS DESIGN FEATURES

**DRAINAGE AREA:** 88 acres  
**LAND USE:** Townhouse  
**DENSITY:** 6.1 DU/acre

**STORAGE VOLUME:** 210,000 cubic feet  
 control the 10 year, 2 hour design storm

## OTHER CHARACTERISTICS:

- 7.5 foot riser
- poorly vegetated
- formerly a sediment trap
- surface area = 1.2 acre

**EFFECTIVE IMPERVIOUSNESS:** 31%  
**WATERSHED SERVICED BY BMP:** 25%  
**SLOPE:** 7.9%

**SOILS:** Loamy Sediments of the Coastal Plain (@ 70% NO "B")

## MONITORING ARRANGEMENT

**CHARACTERISTICS:** Type "H" flumes at inlet and outlet of pond

**STORM EVENTS MONITORED:** 20 synoptic storm events between August 1980 and August 1981; 49 inflow events, 41 outflow events.

## METHOD(S) USED TO CALCULATE EFFICIENCY

Methods A, B, and C. (For explanation see section in this chapter headed Methods Used Analyzing BMP Removal Efficiencies).

Table 2.3  
BMP FACT SHEET: STEDWICK EXTENDED DETENTION STORMWATER POND

## GENERAL FEATURES

**FACILITY NAME:** STEDWICK  
**TYPE OF BMP:** Extended Detention Dry Stormwater Pond  
**LOCATION:** Montgomery Village, in suburban Montgomery County, Maryland

**OPERATION:** Stedwick was modified from a conventional peak shaving dry pond to an extended detention facility. The outflow pipe was replaced with a perforated riser enclosed in a gravel jacket. This modification was designed to detain stormwater runoff for up to 24 hours, instead of the 1 to 2 hours typically observed in conventional dry ponds.

## POLLUTANT REMOVAL MECHANISM(S)

It was hypothesized that the extended duration of stormwater detention would lead to increased settling of particulate pollutants, and that removal of pollutants via chemical flocculation and transformation also might take place.

## WATERSHED CHARACTERISTICS DESIGN FEATURES

**DRAINAGE AREA:** 34 acres  
**LAND USE:** Townhouse  
**DENSITY:** 6.1 DU/acre

**STORAGE VOLUME:** 86,000 cubic feet  
 56% of storage for control of two year design storm. 44% of storage was for nonpoint source control.

## OTHER CHARACTERISTICS:

- high length to width ratio
- well vegetated pond bed
- water passed through pond within a paved channel
- energy dissipating device at outlet

**IMPERVIOUSNESS:** 31%  
**EFFECTIVE IMPERVIOUSNESS:** 20%  
**WATERSHED SERVICED BY BMP:** 100%

**SLOPE:** 4.7%

**SOILS:** Silty Loam soils in Glenage Manor Series

## MONITORING ARRANGEMENT

**CHARACTERISTICS:** Type "H" flumes installed at inlet and outlet of pond. Manning automated samplers took flow integrated water quality samples.

**STORM EVENTS MONITORED:** 25 synoptic storms were monitored between October 1980 and December 1981; 47 at the inflow, 33 at the outflow.

## METHOD(S) USED TO CALCULATE EFFICIENCY

Variation of Method C (Section 2, Long Term Removal Efficiency). Influent and effluent loads were calculated for thirty synoptic storms, using measured EHC's and influent discharge. (For explanation see section in this chapter headed Methods Used Analyzing BMP Removal Efficiencies).

## OTHER NOTES

For reasons which are entirely clear, Stedwick did not achieve designed detention times. Average detention was approximately 4 to 8 hours throughout monitoring period.

Table 2.4  
BMP FACT SHEET: BURKE WET STORMWATER POND

#### GENERAL FEATURES

**FACILITY NAME:** BURKE POND  
**TYPE OF BMP:** Stormwater Retention Pond (WET POND)  
**LOCATION:** Suburban Fairfax County, Virginia  
**OPERATION:** In addition to the required "dry" stormwater management volume, the basin has a permanent pool of water. Water level is determined by the height of the riser and the release of the outflow pipe.

**POLLUTANT REMOVAL MECHANISM(S)**  
Several removal mechanisms are believed to operate in wet ponds. Settling and chemical flocculation should be pronounced due to presence of standing water, and biological uptake by plankton and rooted aquatic vegetation are another candidate for removal as well.

#### WATERSHED CHARACTERISTICS

**DRAINAGE AREA:** 27.1 acres  
**LAND USE:** Medium Density Residential  
**DENSITY:** 3 DU/acres

**IMPERVIOUSNESS:** 34%  
**EFFECTIVE IMPERVIOUSNESS:** 25%  
**WATERSHED SERVICED BY BMP:** 100%  
**SLOPE:** 4.5%  
**SOILS:** Silt loams in Glenelg/Glenville series  
**OTHER CHARACTERISTICS:**  
Average surface area = 0.9 acres  
Maximum surface area = 1.4 acres  
Mean Depth ranged from 3.3 to 3.5 feet  
Significant emergent rooted aquatic vegetation around periphery of pond

#### MONITORING ARRANGEMENT

**CHARACTERISTICS:** Palmer-Bowles Flumes installed at inlet and outlet of pond. Mannings automated sampler, ISCO flow meter.

**STORM EVENTS MONITORED:** 29 synoptic storms were monitored between November 1980 to October 1981, 60 inflow storms, 33 outflow storms.

**METHOD(S) USED TO CALCULATE EFFICIENCY**  
Methods A, B and C were used. (For explanation see section in this chapter headed Methods Used Analyzing BMP Removal Efficiencies).

#### OTHER NOTES

Outflows over the monitoring period were only 63% of inflow volume over the 12 month monitoring period. This reflects the fact that 27 storms which were recorded at the inlet were not registered at the outlet. Most of these storms were very small (less than .15 cfs) and suggest that significant drawdowns occurred within the pond for these small storms. Therefore, the results of the efficiency analysis for this pond are probably quite conservative, since methods A and B were predicated on relative water balance between the inlet and outlet.

Table 2.5  
BMP FACT SHEET: WESTLIEGH WET STORMWATER POND

#### GENERAL FEATURES

**FACILITY NAME:** WESTLIEGH  
**TYPE OF BMP:** Stormwater Retention Pond (WET POND)  
**LOCATION:** In the Westliegh subdivision, in western Rockville, Maryland  
**OPERATION:** In addition to the required "dry" stormwater management, the basin has a permanent pool of water. Water level within the pond is regulated by the height of the riser, and also governed by the diameter of the outflow pipe.

**POLLUTANT REMOVAL MECHANISM(S)**  
Several removal mechanisms are believed to operate in wet ponds. Physical settling and chemical flocculation are thought to be enhanced because of the interaction between the standing water and incoming runoff. Biological uptake by plankton and rooted aquatic vegetation is also believed to be important.

#### WATERSHED CHARACTERISTICS

**DRAINAGE AREA:** 48 acres  
**LAND USE:** Large Lot Single Family Household  
**DENSITY:** 1.2 DU/acres

**IMPERVIOUSNESS:** 24%  
**EFFECTIVE IMPERVIOUSNESS:** 16%  
**WATERSHED SERVICED BY BMP:** 100%  
**SLOPE:** 7.9%  
**SOILS:** Silt loams in Glenelg/Manoz/Ellsok Series  
**OTHER CHARACTERISTICS:**  
Wet Pond Surface Area = 1.2 acre  
Maximum Surface area = 1.5 acre  
Mean Depth ranged from 4.1 to 6.2 acre

#### MONITORING ARRANGEMENT

**CHARACTERISTICS:** 42" Palmer-Bowles Flume installed at inlet to pond, 2.5 foot Type "H" Flume installed at outlet - Manning sampler, ISCO flow meter.

**STORM EVENTS MONITORED:** 45 storm events were monitored between October 1980 and December 1981, 29 storms were synoptic.

**METHOD(S) USED TO CALCULATE EFFICIENCY**  
Methods A, B and C. (For explanation see section in this chapter headed Methods Used Analyzing BMP Removal Efficiencies).

Table 2.6  
BNP FACT SHEET: FAIR OAKS WET STORMWATER POND

#### GENERAL FEATURES

**FACILITY NAME:** FAIR OAKS  
**TYPE OF BNP:** Stormwater Retention Basin (WET POND)  
**LOCATION:**  
**OPERATION:**

#### POLLUTANT REMOVAL MECHANISM(s)

#### WATERSHED CHARACTERISTICS

**DRAINAGE AREA:** 55 acres  
**LAND USE:** Suburban Shopping Center  
**DENSITY:** N/A

#### OTHER CHARACTERISTICS:

**IMPERVIOUSNESS:** 90%  
**EFFECTIVE IMPERVIOUSNESS:** 90%  
**WATERSHED SERVICED BY BNP:** 100%  
**SLOPE:** Not determined  
**SOILS:** Fill Soils

#### MONITORING ARRANGEMENT

**CHARACTERISTICS:** 60" Palmer-Bowling Flume installed at inlet, 2.5' Type "H" Flume installed at outlet. Hannings automated sampler with ISCO flow meter.

**STORM EVENTS MONITORED:** no synoptic storms were measured. Inlet station operated from September 1981 to January 1982, and 11 storms were monitored.

#### METHOD(s) USED TO CALCULATE EFFICIENCY

No estimates were calculated at this site. (For explanation see section in this chapter headed Methods Used Analyzing BNP Removal Efficiencies).

#### OTHER NOTES

Outlet riser was discovered to leak substantially. Because of this no pollutant removal efficiency estimates could be made. Inlet data, however, was used to establish efficiencies for the Rockville porous pavement site, along with 208 data for similar shopping centers sites.

Table 2.7  
BNP FACT SHEET: DUFFIEF GRASSED ROADSIDE SWALE

#### GENERAL FEATURES

**FACILITY NAME:** DUFFIEF  
**TYPE OF BNP:** Roadside Grassed Swale  
**LOCATION:** Near Gaithersburg, Maryland in the Duffief Subdivision

**OPERATION:** Stormwater runoff from residential areas is conveyed along a vegetated depression (see figure below) instead of conventional curb and gutter conveyance systems. Runoff follows these grassed water ways, which are connected by driveway outlets. At the terminus of the swales, a storm sewer collects runoff.

#### POLLUTANT REMOVAL MECHANISM(s)

Grassed swales are believed to filter out pollutants by allowing runoff to infiltrate into the soil profile, where they can be removed by various natural processes. Also, the grass itself is thought to filter out some particulates.

#### WATERSHED CHARACTERISTICS

**DRAINAGE AREA:** 12 acres  
**LAND USE:** Large Lot Single Family Residential  
**DENSITY:** 2.2 DU/acres

#### IMPERVIOUSNESS:

**EFFECTIVE IMPERVIOUSNESS:** 11%  
**WATERSHED SERVICED BY BNP:** 100%  
**SLOPE:** 0.5%  
**SOILS:** Silt loams in the Glenlog series, HQ "g"

**OTHER CHARACTERISTICS:**  
Mean Swale length - 423 feet  
Mean Swale slope - 5.1%

#### MONITORING ARRANGEMENT

**CHARACTERISTICS:** A Type "H" Flume was installed at the downstream terminus of the swale. This flume was integrated with a Hanning automated sampler.

**STORM EVENTS MONITORED:** 8 events were monitored from February 1981 through November 1981.

#### METHOD(s) USED TO CALCULATE EFFICIENCY

Methods B and D were applied using the Westleigh Pond inflow monitor as the control site. (For explanation see section in this chapter headed Methods Used Analyzing BNP Removal Efficiencies).

#### OTHER NOTES

The extremely small size of the sampling effort probably does not represent an adequate basis to draw any conclusions about efficiency. In most efficiency calculations, the Duffief data set was pooled with the Stratton Woods data-set to get a statistically significant sample.

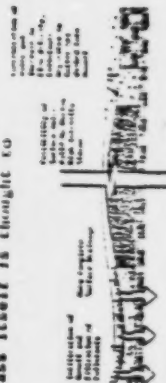


Table 2.8

**BMP FACT SHEET: FAIRBRIDGE GRASSED ROADSIDE SWALE****GENERAL FEATURES**

**FACILITY NAME:** FAIRBRIDGE  
**TYPE OF BMP:** Roadside Grassed Swale  
**LOCATION:** Montgomery Village, Montgomery County, Maryland

**OPERATION:** Stormwater runoff from residential areas is conveyed along a vegetated (grassed) depression along the road, instead of by the conventional curb and gutter systems. Runoff passes under driveways within underground galvanized culvert. A stormwater sewer collects the runoff at the terminus of the swale.

**POLLUTANT REMOVAL MECHANISM(s)**

Grassed swales are believed to filter out pollutants by allowing runoff to infiltrate into the soil profile, where they can be removed by natural processes. Also, the grass is expected to filter out some particulates.

**WATERSHED CHARACTERISTICS**

**DRAINAGE AREA:** 19 acres  
**LAND USE:** Medium Density Single Family Residential  
**DENSITY:** 2.8 DU/acre

**DESIGN FEATURES**

**STORAGE VOLUME:** N/A

**IMPERVIOUSNESS:** 34%

**EFFECTIVE IMPERVIOUSNESS:** 21%

**WATERSHED SERVICED BY BMP:** 90%

**SLOPE:** 4.3%

**SOILS:** Silt loess in Glenog/Honor series

**OTHER CHARACTERISTICS:**

Mean swale length - 445 feet  
 Mean swale slope - 4.1%

**MONITORING ARRANGEMENT**

**CHARACTERISTICS:** 30" Palmer-Boulus Flume installed at the terminus of the swale, equipped with a Manning automated sampler and an 1500 flow meter

**STORM EVENTS MONITORED:** 50 storm events were monitored between October 1980 to December 1981

**METHOD(s) USED TO CALCULATE EFFICIENCY**

Methods B and D were applied using Fairbridge as the experimental site, and the Burke Pond inlet data as the control. (For explanation see section in this chapter headed Methods Used Analyzing BMP Removal Efficiencies).

Table 2.9

**BMP FACT SHEET: STRATTEN WOODS GRASSED ROADSIDE SWALE****GENERAL FEATURES**

**FACILITY NAME:** STRATTEN WOODS  
**TYPE OF BMP:** Grassed Roadside Swale  
**LOCATION:** Stratten Woods subdivision in Reston, Virginia

**OPERATION:** Stormwater runoff from residential areas is conveyed along a vegetated depression along the road, instead of by conventional curb and gutter systems. Runoff follows from grassed swale to grassed swale until it is finally collected by a storm sewer. Galvanized culverts under driveway connect the swales.

**POLLUTANT REMOVAL MECHANISM(s)**

Grassed swales are believed to filter out pollutants by allowing runoff to infiltrate into the soil profile, where they can be removed by natural processes. Also, the grass itself is expected to filter out some particulates.

**WATERSHED CHARACTERISTICS**

**DRAINAGE AREA:** 9.5 acres  
**LAND USE:** Large Lot Single Family Residential  
**DENSITY:** 1.8 DU/acre

**DESIGN FEATURES**

**STORAGE VOLUME:** N/A

**IMPERVIOUSNESS:** 22%

**EFFECTIVE IMPERVIOUSNESS:** 17%

**WATERSHED SERVICED BY BMP:** 100%

**SLOPE:** 1.6%

**SOILS:** Sandy, Silt and Silty Loams in the Brecknock/Penn/Croton series

**OTHER CHARACTERISTICS:**

Mean Swale length - 260 feet  
 Mean Swale slope - 1.8%

**MONITORING ARRANGEMENT**

**CHARACTERISTICS:** 27" Palmer-Boulus Flume at outlet.

**STORM EVENTS MONITORED:** 33 storm events were monitored between October 1980 and October 1981.

**METHOD(s) USED TO CALCULATE EFFICIENCY**

Methods A and D using the Westleigh inflow data as the control. (For explanation see section in this chapter headed Methods Used Analyzing BMP Removal Efficiencies).



Table 2.10  
BMP FACT SHEET: BURKE VILLAGE INFILTRATION TRENCH

#### GENERAL FEATURES

**FACILITY NAME:** BURKE VILLAGE SHOPPING CENTER  
**TYPE OF BMP:** Infiltration Trench  
**LOCATION:** Burke, Virginia

**OPERATION:** A trench was installed adjacent to shopping center parking lot which consisted of a small excavated pit backfilled with coarse stone. This trench was connected to the storm drain system with a small outlet pipe.

#### POLLUTANT REMOVAL MECHANISM(S)

The trench is intended to provide temporary storage of stormwater followed by gradual infiltration into the underlying soil profile, and eventual release through the pipe. Pollutant removal is assumed to occur within the soil profile, or by diversion to groundwater.

#### WATERSHED CHARACTERISTICS

**DRAINAGE AREA:** 4.5 acres  
**LAND USE:** Shopping Center  
**DENSITY:** N/A

#### DESIGN FEATURES

**STORAGE VOLUME:** 11,240 cubic feet  
of void space

**IMPERVIOUSNESS:** 79%

**EFFECTIVE IMPERVIOUSNESS:** 79%

**WATERSHED SERVICED BY BMP:** 99%

**SLOPE:** Not determined

**SOILS:** Silt Loams in the Glenog/Worham Series HQ "g"

#### OTHER CHARACTERISTICS:

the void space represents approximately 1/3 to 1/3 of the volume required to control the two year design storm

#### MONITORING ARRANGEMENT

**CHARACTERISTICS:** 27 inch Palmer-Bowlus Flume at outlet.

**STORM EVENTS MONITORED:** 51 events monitored between September 1980 through December 1981.

#### METHOD(S) USED TO CALCULATE EFFICIENCY

Methods A and B using the Fair Oaks inflow data as a control. (For explanation see section in this chapter headed Methods Used Analyzing BMP Removal Efficiencies).

Table 2.11  
BMP FACT SHEET: DANDRIDGE INFILTRATION PIT

#### GENERAL FEATURES

**FACILITY NAME:** DANDRIDGE  
**TYPE OF BMP:** Infiltration Pit  
**LOCATION:** Townhouse development at the Fairfax/Vienna line, in Virginia

**OPERATION:** Stormwater from the townhouse development was directed into three parallel subsoil gravel trenches, which were drained by 6" perforated tile drains and conveyed to an outlet.

#### POLLUTANT REMOVAL MECHANISM(S)

Rapid infiltration into the soil profile was hypothesized to filter out particulate pollutants. Also, some component of the total runoff load was expected to be routed to the groundwater.

#### WATERSHED CHARACTERISTICS

**DRAINAGE AREA:** 2.5 acres  
**LAND USE:** Townhouse  
**DENSITY:** 16 DU/acre

#### DESIGN FEATURES

**STORAGE VOLUME:** 4,080 cubic feet  
of void space

**IMPERVIOUSNESS:** 55%

**EFFECTIVE IMPERVIOUSNESS:** 34%

**WATERSHED SERVICED BY BMP:** 46%

**SLOPE:** 3.6%

**SOILS:** Silt Loams in the Glenog Series, HQ "g"

#### OTHER CHARACTERISTICS:

perforated 6" tile drains

#### MONITORING ARRANGEMENT

**CHARACTERISTICS:** 1.5" Palmer-Bowlus Flume installed at outlet of tile drains

**STORM EVENTS MONITORED:** 46 storm events monitored between September 1980 through December 1981.

#### METHOD(S) USED TO CALCULATE EFFICIENCY

Methods B and D using Lakeridge and Stedwick inflows as a control. (For explanation see section in this chapter headed Methods Used Analyzing BMP Removal Efficiencies).

#### OTHER NOTES

At the Dandridge site, slightly over 50% of the runoff monitored at the outlet was from uncontrolled areas (i.e., drainage not entering the infiltration device). This feature may be responsible for masking some of the potential pollutant removal which might have been taken place.

Table 2.12  
BMP FACT SHEET: ROCKVILLE POROUS PAVEMENT

**GENERAL FEATURES**

FACILITY NAME: ROCKVILLE CITY CENTER  
TYPE OF BMP: Porous Pavement Site  
LOCATION: Rockville, Maryland

OPERATION: Stormwater collected from 1.2 acres of conventional pavement passed over porous pavement section (2.0 acres). The porous pavement was of the "popcorn" pore variety. Stormwater passed below pavement through a gravel bed into the soil drain, and was collected by 6" perforated tile drains. This water is subsequently conveyed to the outlet monitoring area.

**POLLUTANT REMOVAL MECHANISM(s)**

Rapid infiltration of stormwater through pores in the asphalt, and subsequent adsorption to binding sites within the soil matrix were hypothesized to remove a significant percentage of pollutants by chemical, physical and biological processes. Also some component of the runoff volume is assumed to be lost to the groundwater.

**WATERSHED CHARACTERISTICS**

DRAINAGE AREA: 4.2 acres  
LAND USE: Office Complex  
DENSITY: N/A

IMPERVIOUSNESS: 70%  
EFFECTIVE IMPERVIOUSNESS: 70%  
WATERSHED SERVICED BY BMP: 48%  
SLOPE: 2.6%  
SOILS: Silt Loams in the Gleneg Series, HG "B"

**DESIGN FEATURES**

STORAGE VOLUME: 27,400 cubic feet of void space in the 2 acre porous pavement area.

**OTHER CHARACTERISTICS:**

**MONITORING ARRANGEMENT**

CHARACTERISTICS: 0.75' Type "H" Flume installed at stormwater conveyance system below the tile drains.

STORM EVENTS MONITORED: 35 storm events between February and November, 1980.

**METHOD(s) USED TO CALCULATE EFFICIENCY**

Method "3", comparing the median loading rates from the Fair Oaks site and at two 208 shopping center sites. (For explanation see section in this chapter headed Methods Used Analyzing BMP Removal Efficiencies).

## METHODS FOR MONITORING BMPs

The field sampling for the monitoring of urban BMP pollutant removal effectiveness was conducted by Virginia Polytechnic Institute's Occoquan Watershed Monitoring Laboratory (OWML). This section briefly summarizes this field sampling program conducted between September 1980 and January 1983. A complete description of the equipment installations and procedures used in field sampling can be found in Chapters 2 through 6 in the Final VPI Contract Report (OWML, 1983). The reader is encouraged to examine the VPI report closely to learn more about the site instrumentation, field and lab methods, and data management techniques which were an integral part of the overall project.

### Major Features of the Monitoring Apparatus

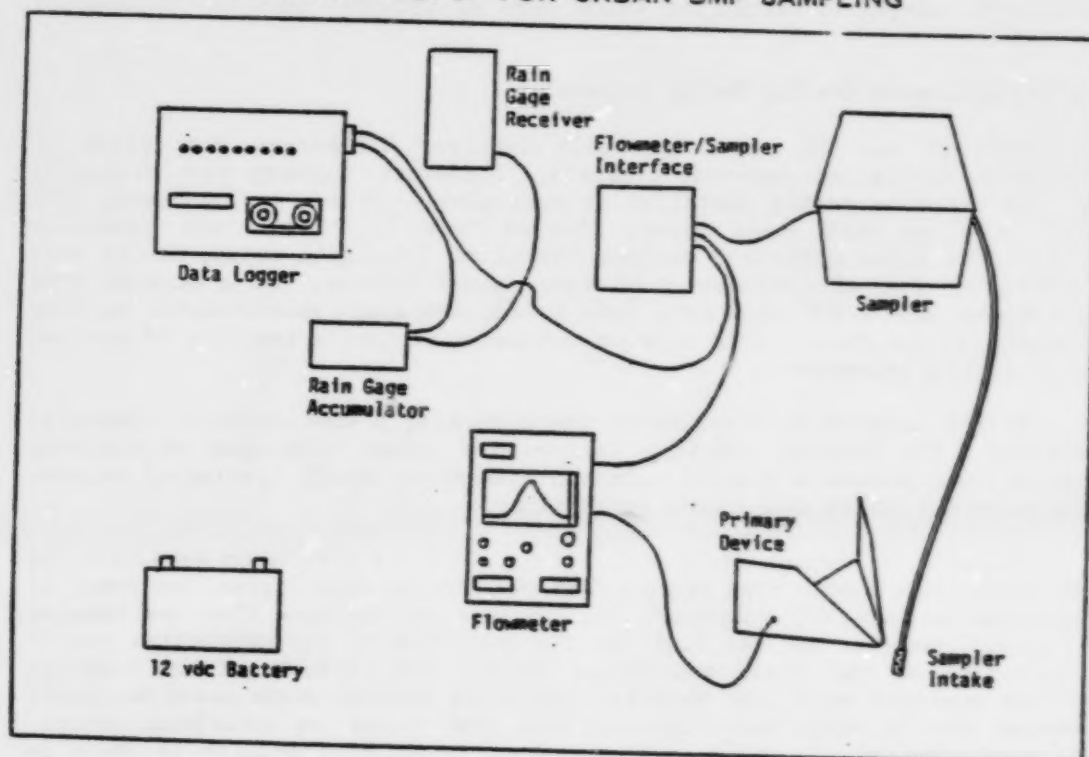
Most of the BMP sites generally involved discharges from pipes or regularly configured man-made channels. Therefore, primary flow measuring devices could be easily installed at most sites. Palmer-Bowlus flumes were used at sites with round pipes, whereas Type-"H" flumes were generally utilized at sites with well defined channels. Discharge rating tables were established for all primary flow measurement devices, and a bubbler type flow-meter and EPROM chip were used to convert stage measurements to flow readings in the field. This allowed automated composite sampling of desired water quality parameters.

Runoff samples were collected using Manning S-4040 portable automated samplers. The Manning sampling devices use vacuum techniques to withdraw samples, and possess a special metering chamber to ensure that equal volumes are collected during each sample activation.

All data on station flows and periods of sample activation were recorded and stored on cassette tape using a portable control data logger, for eventual reduction on the VPI computer. Maintenance of accurate flow and sampler activated records was critical to the assurance of representative sample compositing at the field monitoring sites. End products of the sampling methods employed were flow weighted composite samples which could be easily reduced into an event mean concentration (EMC) value for individual storms. The configuration of equipment at a typical monitoring station is shown in Figure 2.1.

Monitoring equipment was housed in mounted fiberglass enclosures. Each station was visited by OWML personnel at least once a week to perform routine maintenance and verification checks. Stormwater runoff samples were collected within 12 hours of the activation of the field sampler, refrigerated, and transported to the laboratory. Samples were analyzed using accepted analytical techniques (which are summarized in Table 5.2 of the OWML contract report, (OWML, 1983) along with the quality assurance/quality control plan). Measurements were made for plant nutrients, suspended solids, organics, heavy metals, bacteriological forms, and various physical parameters. A complete list of the parameters analyzed can be found in Table 15.

Figure 2.1  
MONITORING SETUP FOR URBAN BMP SAMPLING



SOURCE: Occoquan Watershed Monitoring Laboratory, 1983.



## Monitoring Arrangements for Different BMP Types

The monitoring arrangement for each of the BMPs varied considerably. For the dry and wet pond BMPs, stations were installed at the inlet and outlet of each structure. This allowed for a direct comparison of Event Mean Concentrations (EMCs) in runoff entering and leaving the BMP (after correcting for the potential for slightly different drainage areas at the inlet and outlet of the pond).

Because infiltration controls accept diffuse runoff flows from a broad area it is not physically possible to monitor inflow runoff quality at volume-control BMPs sites (i.e., grassed swales, infiltration devices, porous pavements). Therefore monitoring only occurred at the point where runoff was discharged from infiltration structures. The study design called for sampling equipment to be installed at the outlet of each structure, and for comparisons of observed loading data from the outlet to be made with loading data from similar land use types which were monitored without any BMP controls. Loading comparisons were made between sites having similar land use, density, and degree of imperviousness. It was not possible to pair controlled and uncontrolled sites of similar land use which also had the same general location and precisely the same soil and slope characteristics. Because of this experimental limitation, the results of the BMP efficiency analysis for volume control devices should be viewed as providing general comparisons of relative pollutant removal behavior rather than precise removal rates.

Table 2.13  
WATER QUALITY PARAMETERS MONITORED IN THE BMP  
EFFECTIVENESS STUDY

|                            |                      |
|----------------------------|----------------------|
| Plant Nutrients            | Bacteriological      |
| TOTAL NITROGEN             | Total Coliforms*     |
| Nitrate + Nitrite          | Fecal Coliforms*     |
| Total Kjeldahl Nitrogen    | Fecal Streptococci*  |
| Soluble Kjeldahl Nitrogen  |                      |
| Ammonia                    |                      |
| TOTAL PHOSPHORUS           | Trace Metals         |
| Total Soluble Phosphorus   | Extractable/Soluble  |
| Ortho-Phosphate            | Cadmium              |
| Total Suspended Solids     | Copper               |
| Oxygen Demanding Materials | Iron                 |
| COD*                       | Lead                 |
| BOD                        | Nickel               |
|                            | Zinc                 |
|                            | Physical Parameters  |
|                            | pH                   |
|                            | Specific Conductance |
|                            | Temperature*         |

\* Periodic.

## METHODS USED FOR ANALYZING BMP POLLUTANT REMOVAL EFFICIENCIES

A variety of methods were employed to develop removal efficiency estimates for each of the urban BMP's analyzed. The methods used in each case were dependent on the monitoring arrangement for the BMP site as well as the suitability of the data set for analysis (e.g. the number of synoptic storms monitored). Removal estimates were based on both arithmetic and statistical methods. These general methods are described in detail below:

### Method A: Mean Storm Event Efficiency

This method was applied only to wet and dry pond BMPs which had an operating sampling monitor at both the inlet and outlet of the structure. As such, it could not be applied to evaluate volume control BMP efficiencies.

Synoptic storms (i.e., events monitored at both inlet and outlet) were screened to identify those pairs in which inflow and outflow were in reasonable agreement. These resulting pairs were then normalized to account for water balance errors such as pond drawdown due to evaporation loss in wet ponds. Other adjustments included corrections to account for difference in the drainage areas of inflow and outflow monitoring points by converting observed EMC's into loading rates (i.e., lbs/acre). Pollutant removal efficiency was calculated for each event using the formula shown in Panel A of Figure 2.2. Individual storm event efficiency estimates were subsequently summed and divided by the number of storms to arrive at the mean or average removal rate.

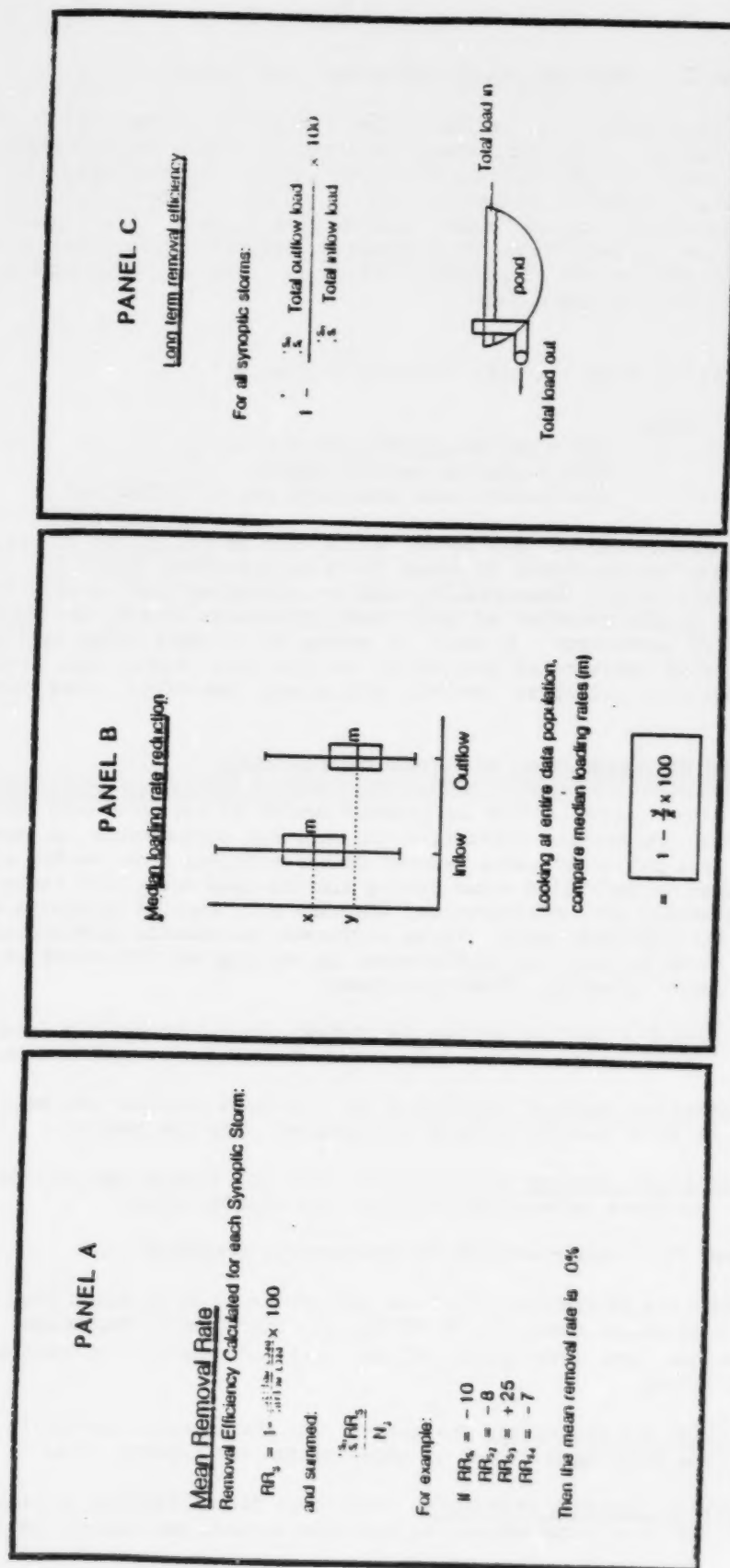
### Method B: Median Loading Rate Reduction

An alternative approach for calculating removal efficiencies was employed which utilized the entire data-set which was generated at each BMP station. In this method, the event mean concentration (EMC) for each storm was multiplied by the total flow, and normalized to account for area and depth of runoff. The resulting storm load was expressed in pounds per acre per inch of runoff. The entire population of inflow and outflow storm loads for all events were analyzed statistically, and the storm loadings at the inlet and outlet for the median loading event were directly compared. Figure 2.2 (Panel B) illustrates how removal rates were computed by this method.

### Method C: Long Term Removal Efficiency

The previous two methods were oriented toward providing removal estimates for a particular kind of storm event or loading condition. Of perhaps greater interest to engineers and planners is the typical long term removal efficiency for a given BMP, since the variation in efficiency for individual storm events can often be significant. This long term estimate is conceptually simple in nature. Basically, mass loadings measured entering and leaving the pond over the entire monitoring interval were summed separately and evaluated using the formula shown in Figure 2.2 (Panel C).

Figure 2.2  
METHODS USED TO CALCULATE POLLUTANT REMOVAL  
EFFICIENCY OF URBAN BMPs



#### Method D: Stepwise Linear Regression Techniques

Individual efficiency estimates for individual storms were analyzed in a multivariate regression model to identify those characteristics which best describe the efficiency of wet ponds. Factors examined included drainage area, permanent pool volume, imperviousness, inflow concentration, inflow volume, and outflow volume. Of all these factors, only the latter three were found to produce a correlation that was significant at the 95 percent confidence interval. The general form of the statistical model was:

$$\text{Removal (\%)} = 100 - a(\text{Qin})^{b_1} + (\text{Qout})^{b_2} + (\text{Cin})^{b_3}$$

Where:

Qin = inflow runoff (inches)

Qout = outflow runoff (inches)

Cin = event mean concentration of inflow (mg/l)

A complete discussion of this model, along with an evaluation of its prediction accuracy can be found in pages 74-76 of the NVPDC final NURP contract report (NVPDC, 1983). Essentially, this technique was used to provide an indication as to the behavior of individual pollutants within wet ponds under varying storm conditions. As such, it serves to increase understanding about the complicated dynamics of wet ponds, and provides statistical predictions of the specific pollutant removal efficiency associated with individual storms.

#### Method E: Comparison of Parametric Statistics

For volume controls such as grassed swales it was necessary to use traditional parametric statistics to test for differences in runoff and unit area pollutant loads between runoff outflows from the BMP structure and from uncontrolled sites having similar land uses. All tests assumed a log-normal data distribution, and were only applied to equivalent runoff distribution data. Three different parametric statistical tests were used to identify differences in loading distributions at the 95% confidence interval. These included:

One-sided K-S testing procedures to test for differences in loading distributions of the controlled and uncontrolled runoff datasets.

T-statistics testing procedures to determine whether the mean loading rates of the BMP dataset is different from its control.

F-Statistics testing procedures to check for significant differences in variances between experimental and control sites.

#### Method F: Comparisons of Non-parametric Statistics

Another set of statistical tests was performed as an additional check on the statistics generated by METHOD E. These tests emphasized the distribution free description of the data and involve the ranking of the data values.

Two sided K-S procedures designed to test for significant differences in the data distribution in experimental and control sites.

Wilcoxon Rank-Sum procedures which test for difference in central values (i.e., the median) of the experimental and control data sets.



## RESULTS OF THE BMP-EFFECTIVENESS ANALYSIS

In this section, an analysis of the pollutant removal effectiveness of the individual BMP types which were monitored is presented. Reference is also made to the comparative efficiency of different BMPs.

### Dry Stormwater Ponds

Overall, the dry pond investigated in the Washington area NURP study did not perform as an effective best management practice. Removal rates varied considerably during most storms (e.g., sediment removal ranged from positive 98 percent to negative 300 percent). The general trend, however was towards negligible or even negative efficiency for most parameters of interest. This is readily apparent in Figure 2.3 in which the removal rates for six water quality parameters are illustrated as determined by the application of METHODS A, B and C. Although there is some variation in the removal efficiency calculated by each method, the overall prognosis of the effectiveness of the dry pond in runoff quality control is poor. For example, the long term removal rate (METHOD C) was 14 percent for total suspended solids, 0 percent for Chemical Oxygen Demand (COD), generally less than 20 percent for various nutrient species, and negative for zinc. These results are especially noteworthy since the estimate of long term pollutant removal efficiencies developed under METHOD C, typically provides a higher estimate of removal efficiency than either Method A or Method B.

The poor to mediocre performance observed at the dry pond site is probably related to several factors. First, the brief residence time of stormwaters within the structure (usually less than 2 hours) severely limits the degree to which physical and chemical pollutant removal can take place. Secondly, the lack of permanent water storage precludes removal by biological means. Thirdly, the substantial number of storms with negative efficiencies suggests that the poorly vegetated pond bed was prone to scour and erosion. Resuspension of previously deposited materials was also thought to be an important factor relating to poor performance of the pond.

### Extended Detention Dry Ponds

Extending the duration of detention times in dry stormwater basins through modification of the outflow structure appeared to be promising as a method for improving removal efficiencies. Removal of particulate forms of urban pollutants (as calculated with METHOD C) was typically high, and on the same order of those reported for wet ponds. For example, sediment removal was approximately 64 percent, organic nitrogen removal was 30 percent, and reductions in COD were 30 percent. Removal rates for trace metals were even higher. Fifty-seven percent of the zinc and 84 percent of the lead entering the pond was retained. However, removal of soluble nutrient forms was minimal, with only 1 percent of the ortho-phosphorus and only 10 percent of the nitrate-nitrogen being removed in the long term. Removal of total nitrogen and total phosphorus was also quite low; in both cases less than 15 percent of the incoming nutrients were removed.

Much of the explanation for the improved pollutant removal performance can be directly attributed to the extended detention achieved. Although the pond did not achieve the detention times for which it was originally designed, the degree of detention which was accomplished was still sufficient to remove particulates effectively. Settling column studies conducted by VPI's OWML (1983) described later in this chapter confirm this belief. Other

Figure 2.3  
COMPARISON OF INDEPENDENT METHODS USED TO CALCULATE  
REMOVAL EFFICIENCIES OF DRY POND BMPs

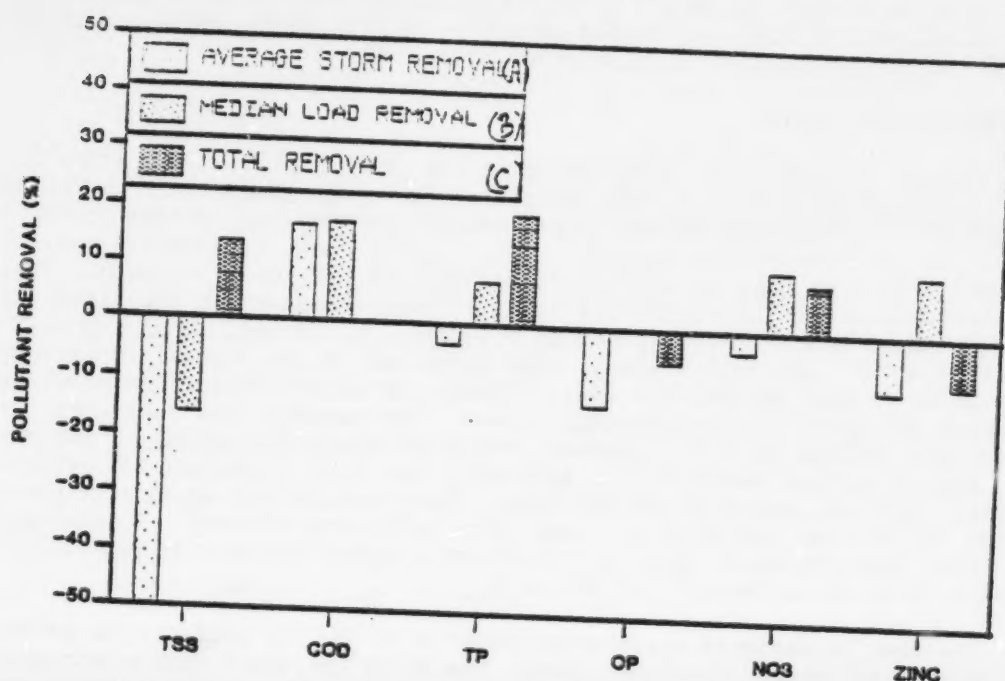
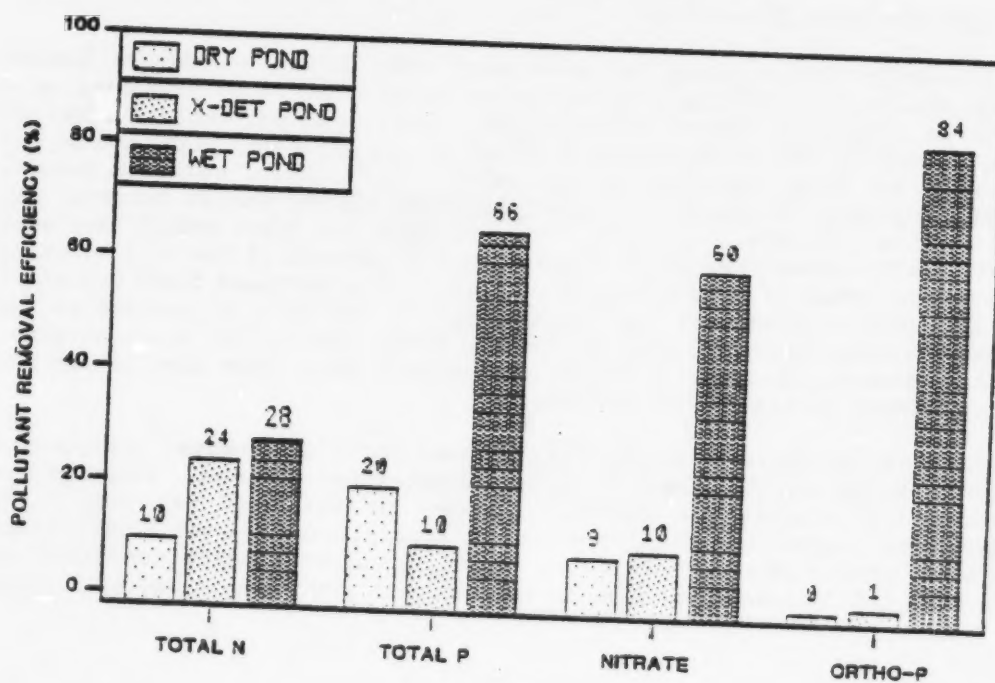


Figure 2.4  
POLLUTANT REMOVAL EFFICIENCIES ASSOCIATED WITH SELECTED  
STORMWATER POND BMPs: NUTRIENTS



design features that contributed to the high removal of particulates were the paved channel at the pond's bottom and the established vegetation within the pond bed. These features reduced the likelihood of scour or resuspension, which would tend to reduce the pollutant removal efficiency of the pond.

### Wet Ponds

Wet ponds were found to be one of the most effective BMPs studied for nonpoint source control. These ponds were observed to remove a significant portion of soluble nutrient forms. As can be seen in Figure 2.4, the high removal rate of soluble nutrients such as ortho-phosphate and nitrate was in sharp contrast to the minimal removals noted at the dry pond and/or extended detention pond sites. These data suggest the importance of biological uptake in wet ponds as an effective removal mechanism for biologically-available nutrients. Long term removal rates for particulate pollutants in wet ponds were also high and surprisingly comparable to the rates demonstrated for extended detention ponds as shown in Figure 2.5. For the pooled wet ponds, removal rates for suspended sediments were 54 percent, COD removal was approximately 30 percent and organic nitrogen reductions were 15 percent. Total phosphorus reductions were 64 percent. (It should be noted that the Westleigh wet pond consistently out-performed the Burke wet pond for nearly all particulate pollutants. As mentioned in Table 4.4, the suspected draw-down at Burke may have caused efficiency estimates for the pond to be too conservative.)

Observed removal rates for trace metals were also consistently high. Pooled long term removals for zinc and lead were 51 and 65 percent, respectively. The deposition of trace metals within pond sediments was confirmed in sampling conducted within the pond bed (OWML, 1983). Pond sediments had been enriched to levels approaching the metal content of domestic sludge. However, no downward migration of these metals into the soil was observed.

Application of the METHOD D multi-variate regression model shed some interesting light on wet pond behavior. This analysis suggested that removal efficiency sharply increased for most particulate pollutants as the size of the storm increased (Figure 2.6). This fact helped to explain several seemingly incongruous results of the wet pond efficiency analysis. For example, removal rates for some parameters fluctuated widely from storm to storm. However, upon closer scrutiny, many of the storms with lower efficiencies were found to be of relatively small size, which was consistent with the results of the multi-variate regression models. (i.e., smaller storms were predicted to have lower removal efficiencies.) Similarly, the larger storms tended to have much greater removal efficiencies.

Figure 2.7 compares the removal rates observed in wet ponds for particulate pollutants such as sediment, COD, total phosphorus, with the dissolved nutrients ortho-phosphate and nitrate. The long-term removal efficiency for all storms (METHOD C) for the particulate constituents was generally higher than the removal rates estimated with either the mean (METHOD A) or median (METHOD B) efficiency. Since the large storms produce the majority of the annual load of particulate pollutants, the greatest removal efficiency is shown with the long-term method. This is also evidenced by examining those constituents which do not exhibit such a dramatic increase in load as storm size increases (such as ortho-phosphate or nitrate). For these nutrient forms, it would be expected that the three estimation methods would converge and give essentially similar results. As can be seen in Figure 2.7, this is exactly the behavior which was observed in wet ponds.

Figure 2.3  
COMPARATIVE POLLUTANT REMOVAL EFFICIENCY OF WET  
AND EXTENDED DETENTION STORMWATER PONDS

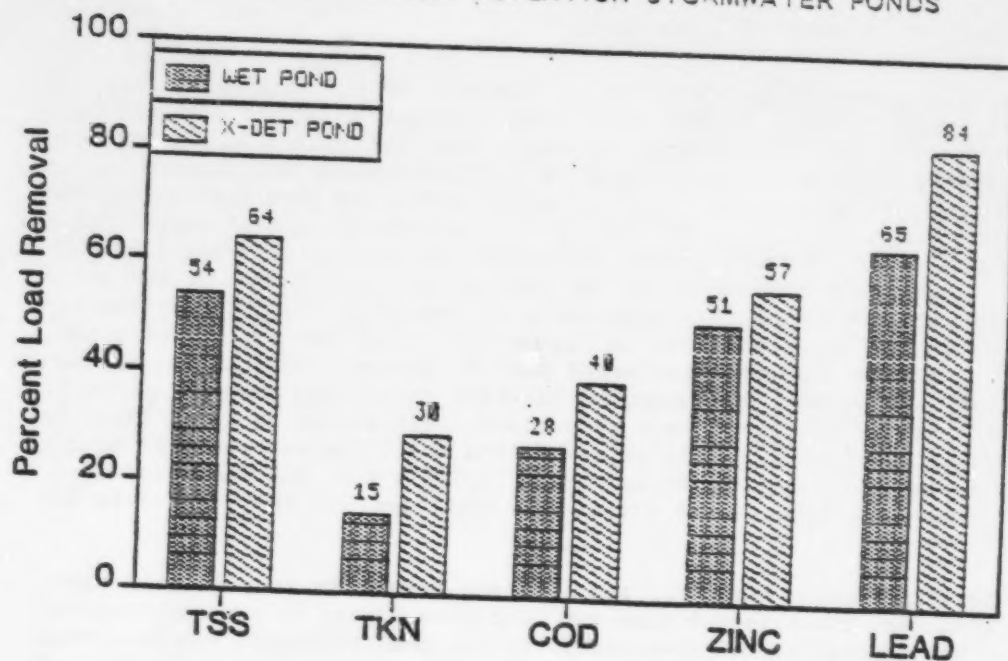


Figure 2.6  
RELATIONSHIP BETWEEN STORM SIZE AND SEDIMENT REMOVAL

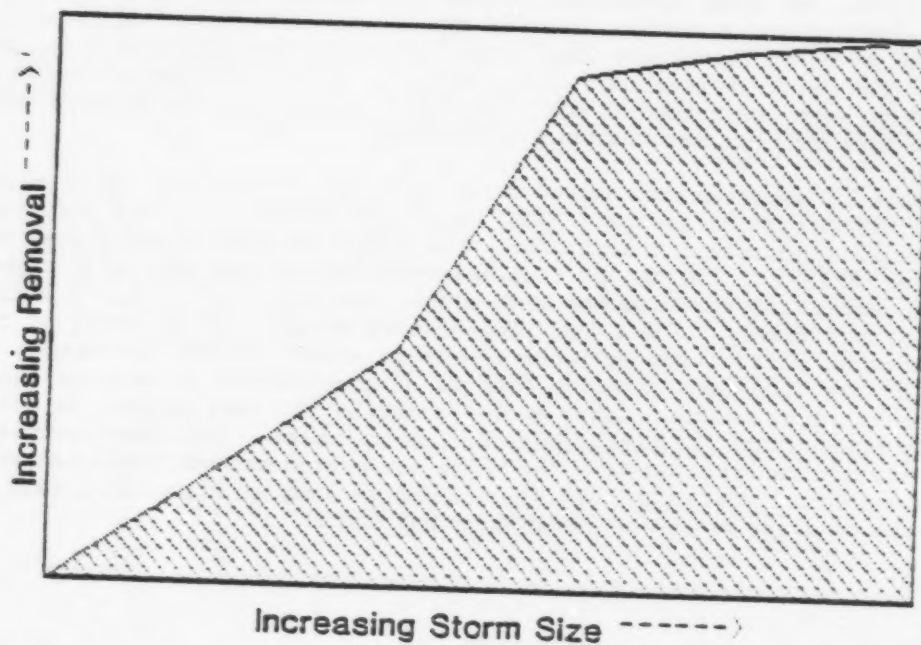




Figure 2.7  
COMPARISON OF INDEPENDENT METHOD, USED TO CALCULATE  
REMOVAL EFFICIENCIES OF NET STORMWATER POND BMPs

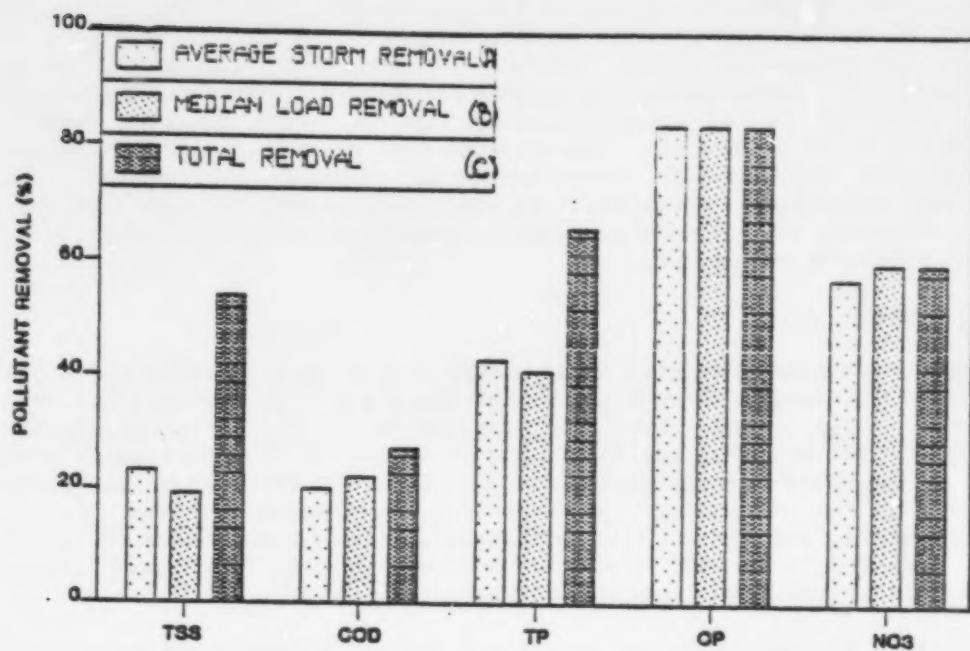
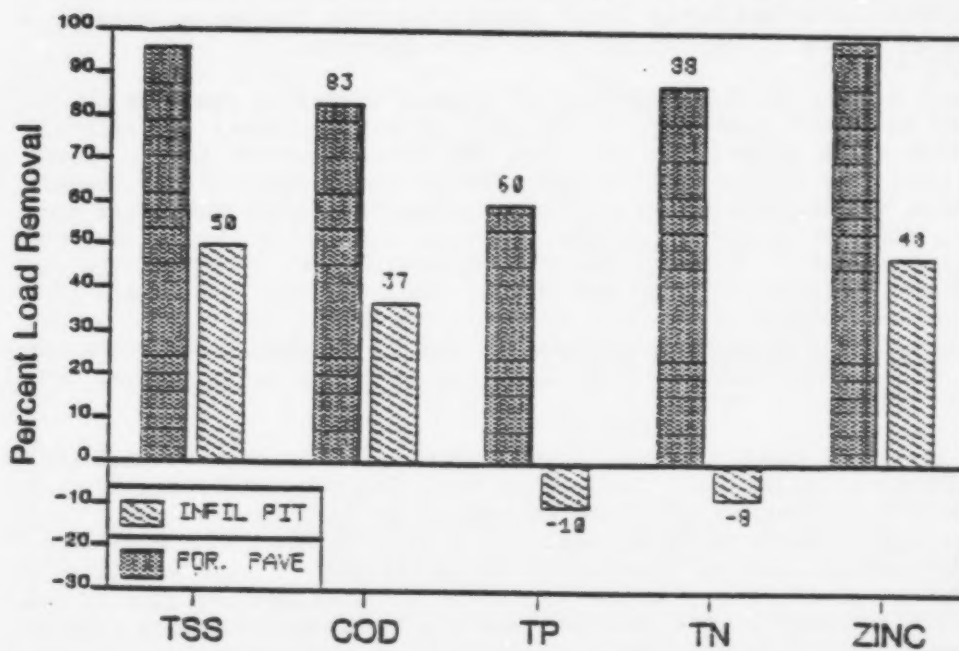


Figure 2.8  
COMPARATIVE POLLUTANT REMOVAL PERFORMANCE OF POROUS  
PAVEMENT AND INFILTRATION TRENCH BMPs



Operative mechanisms for achieving pollutant removal in wet ponds are manifold, including deposition, chemical flocculation/transformation and biological activity. Based on a comparison of component nitrogen efficiencies, it appears that biological uptake is the predominant removal mechanism for nitrate. Deposition, rather than oxidation, seems to be the primary removal mechanism for organic nitrogen. Depositional processes also appear to be fully capable of accounting for the organic phosphorus removal observed. Uptake by algae or rooted aquatic plants seems to be the dominant removal mechanism for ortho-phosphorus. The striking similarity in removal rates observed in wet and extended detention ponds (Figure 2.5) implies that depositional processes, such as settling and flocculation, are more than sufficient to explain the observed patterns in removal rates for sediments, COD, and trace metals in wet ponds.

### Grassed Swales

Comparisons were developed between the runoff loads leaving the three grassed swale drainage system sites versus the loads from conventional curb and gutter systems. Based upon these comparisons, no statistically significant improvement in runoff quality from grassed swales could be demonstrated for any of the water quality parameters analyzed. In fact, when the entire BMP data set was analyzed, significantly higher median loadings of COD, ortho-phosphorus, ammonia and zinc were noted in the grassed swales (Method B and E). However, with the exception of zinc loadings, (discussed later) these results probably only represent statistical "noise".

Lysimeter studies conducted in grassed swales by OWML found no statistically significant enrichment of trace metals within the soil profiles underlying grassed swales when compared to adjacent curb or lawn soil metal concentrations. This finding suggests that trace metals did not settle out in the grassed swales and were not effectively removed from runoff. The presence of enhanced levels of zinc in the runoff of grassed swales could be attributed to mobilization of zinc anions from the galvanized culverts which carried runoff under the driveways at the monitored sites. Field studies by the OWML (1983) have implicated "acid" rainfall within the region as being a possible cause of the release of zinc from these culverts.

To some degree, the effectiveness of grassed swales in removing pollutants could have been masked by differences in soils, slopes and rainfall distributions which occurred at the curb and gutter control sites. There certainly were some differences in these factors which could affect comparisons between the Stratton Woods swale and the Westleigh curb and gutter control site, and, to a lesser extent, between the Dufief swale and the Westleigh control site. However, the most representative comparison, the one for Fair Ridge swale/Burke curb and gutter, indicated that this swale also had negligible or negative removal rates for the entire spectrum of pollutants analyzed. The conclusion reached was that if grassed swales have any pollutant removal capability, it certainly could not be distinguished from background loadings.

Why, then, did grassed swales appear to perform so poorly? Several reasons are offered. First, all swale sites monitored were underlain by silt loam soils, the predominant soil type in most of the Washington region. Such soils lack the porosity of other soils in A or B hydrological groupings. Second, the contact time of stormwater within the swale system was usually only on the order of 5 to 10 minutes, whereas the infiltration rate of the silt loam soils underlying the swale systems which were monitored was considerably greater. As a result, little infiltration of stormwater into the soil

profile apparently occurred. Thirdly, the slopes within the swales themselves ranged from 4 to 6 percent. This probably led to high water velocity and substantial downstream head. In many of these sloping grassed swales, stormwater quickly matted the grass, and the flow regime distinctly resembled open channel conditions. Finally, the grass within the residential swales was frequently mowed, and as a result, did not act as an effective natural filter. Research in New Hampshire (Oakland, 1983) reported low to moderate removals of particulates in a grassed swale with pure stands of 12 inch tall reed-canary grass, which suggests that dense vegetation is required to achieve a significant filtering effect.

Although no stormwater or pollutant removal benefits could be attributed to the swale sites monitored in the Washington area, it is believed that certain design modifications to swale systems could increase their effectiveness as BMP's. For example, permeable gravel filters, energy dissipators, or ponding mechanisms could be installed to slow runoff and enhance pollutant removal by infiltration. Also, application of grassed swales on more permeable soils, such as those in hydrological groups A and B, might also improve efficiencies. In addition, the implementation of swales on gentler slopes would be beneficial. And finally, the use of swales on the flat coastal plain topography and soils might be advantageous, since water velocity and downstream heads would not overwhelm the infiltration capacity within the swales.

#### Infiltration Controls

Results from the monitored infiltration BMP sites were somewhat difficult to assess for several reasons. First, the two sites, Burke Center and Dandridge, had different designs, storages and land uses. As a result, the removal efficiencies of these infiltration controls should be analyzed on a case by case basis. Secondly, a comparison of loadings from the Dandridge facility with runoff loadings monitored from the Stedwick Pond inflow point (which was intended to represent a similar land use unaffected by BMP controls) appeared to be inappropriate upon further field investigations of site characteristics. Due to apparent discrepancies between the site plans for the area drainage system with actual on-site grading and drain construction, it was discovered, after the monitoring data had been collected and analyzed, that over half the loads monitored at Dandridge were not controlled by the infiltration system. Also, its control site had a different precipitation distribution and had 20 percent less imperviousness cover within its drainage area. While none of these factors alone would prevent the development of useful comparisons, it was felt that in combination they tended to significantly bias the results against the infiltration facility. This was seen in the median loading rate removals calculated for Dandridge infiltration facility. For sediment, total nitrogen, COD, Zinc, and Lead, negative efficiencies were recorded in excess of 66 percent (and ranging up to -267 percent). It would be difficult to conceive a mechanism having such prolific pollutant generation in the absence of any known sources of pollutants within the device itself. As a result, the Dandridge/Stedwick site comparison was judged to be invalid, and as such, the comparison was not considered to be representative of pollutant removal benefits attributed to volume controls. Unfortunately, there was no other Washington area NURP site which has similar characteristics to Dandridge which could be used for comparison.

Fortunately, the Burke Center infiltration trench/Fair Oaks control comparison was much more representative. In general, the Burke Center infiltration trench was found to have significant potential as an effective BMP. Median loading rate reductions on the order of 50 percent were observed for

sediments and trace metals. COD removal was estimated to be 37 percent. Nutrient removal, however, was negligible or non-existent. (This is not altogether surprising since there are in all likelihood very few biological removal mechanisms operating within the coarse gravel of the Burke trench). These removal estimates, must be considered provisional given the inherent limitations of the comparisons noted earlier. Also, the Burke Center infiltration trench is only one of many kinds of designs for infiltration structures. As such, the removal estimate strictly applies only to the Burke trench site. Further field research is being planned by the Maryland Department of Natural Resources to investigate the effectiveness of other infiltration design concepts.

### Porous Pavement

The porous pavement site proved to be a very effective best management practice with respect to control of both water quantity and quality. For most storms, the duration of the runoff event was extended by up to 24 hours, and peak discharges were dramatically shaved. Extremely high removal rates (in excess of 80 percent) were observed for sediments, COD, total nitrogen and trace metals (see Figure 2.8). Removal of phosphorus and soluble nitrogen forms was also in excess of 60 percent. These removal rates were calculated with Method B using the Fair Oaks inflow and two shopping centers monitored during an earlier study (NVPDC and VPI&SU, 1978) as uncontrolled equivalent sites for the sake of comparison. As can be seen in Figure 10, the removal efficiency for the porous pavement site was considerably greater than the second most efficient infiltration device, the Burke Center infiltration device.

The chief removal mechanisms that appeared to be operating to such great effect in the porous pavement site were the rapid and complete infiltration runoff into the soil profile, and subsequent adsorption, trapping and chemical decay within this zone. Also, a sizeable component of the runoff and pollutant load may have been routed to the groundwater pool, and thus be removed.



## GENERAL DESIGN FEATURES WHICH ENHANCE POLLUTANT REMOVAL IN STORMWATER MANAGEMENT DEVICES

The results obtained in the analysis of runoff loading data from individual BMPs and the special studies conducted by OWML suggest several design principles that can enhance the pollutant removal capability of urban stormwater management structures. These principles are:

- Extending detention times in conventional "dry" stormwater ponds.
- Preparing the bed of dry ponds to minimize scour and resuspension.
- Encouraging rapid infiltration and prolonged soil contact time in infiltration devices.
- Utilizing the physical and biological removal processes of wet ponds.

Each of these design concepts are discussed at greater length below.

### 1. Increasing Detention Time

The superiority of extended detention ponds over the conventional detention (dry) pond in removing particulates has been demonstrated in earlier sections. The major advantage of extended detention is that it provides more time for pollutants to be removed by gravity sedimentation (i.e., physical settling and coagulation). This impression is reinforced by settling column experiments conducted by the OWML as a special study for the NURP project.

In this experiment, seven urban stormwater samples collected from commercial areas were introduced into a six foot plexiglass settling chamber. Sampling ports were located at every foot along the settling chamber, and samples were withdrawn at intervals of 2, 6, 12, 24 and 48 hours. The downward movement of pollutants was measured, and a removal rate was calculated, based on the percentage of influent concentration which migrated to a four foot depth.

These experiments provided data that shed some interesting light on the settling dynamics of urban stormwater, and on the degree of removal which could be achieved through settling processes alone. One important result was that the settling rate for most parameters was extremely sensitive to the initial concentrations, such that the highest settling rates were almost always associated with the stormwater samples which had the greatest initial concentration (Figure 2.9). Also, most of the constituents in the stormwater runoff samples behaved like a mixture of discrete and flocculant solids, with discrete solids rapidly settling out (within a few hours) while the flocculant solids gradually settled over a period of several days. The practical implication of this phenomenon is that the removal rate for most constituents was logarithmic in nature. This is best exemplified in the sediment settling data illustrated in Figure 2.9. As can be seen, 65 percent of the sediment removal occurs within the first six hours, while the next 15 percent removal increment takes another 42 hours to occur. Therefore, the design of extended detention ponds might be oriented toward achieving a 6 to 12 hour detention

Figure 2.9  
RELATIONSHIP BETWEEN SEDIMENT REMOVAL RATE, INFLUENT  
CONCENTRATION AND SEDIMENTATION TIME: EXPERIMENTAL  
SETTLING COLUMN STUDIES

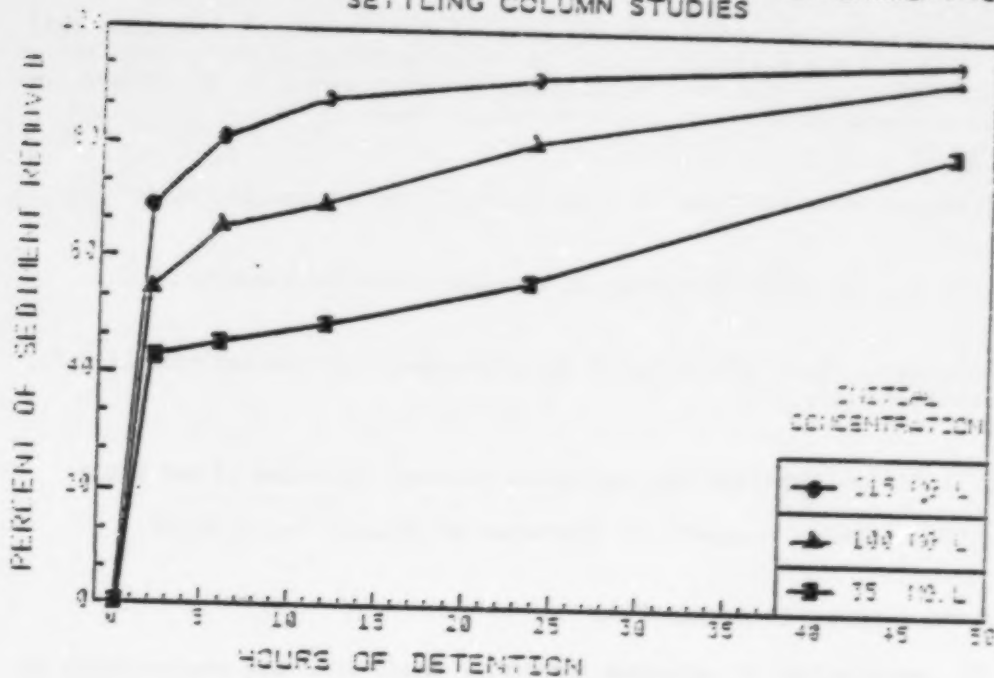
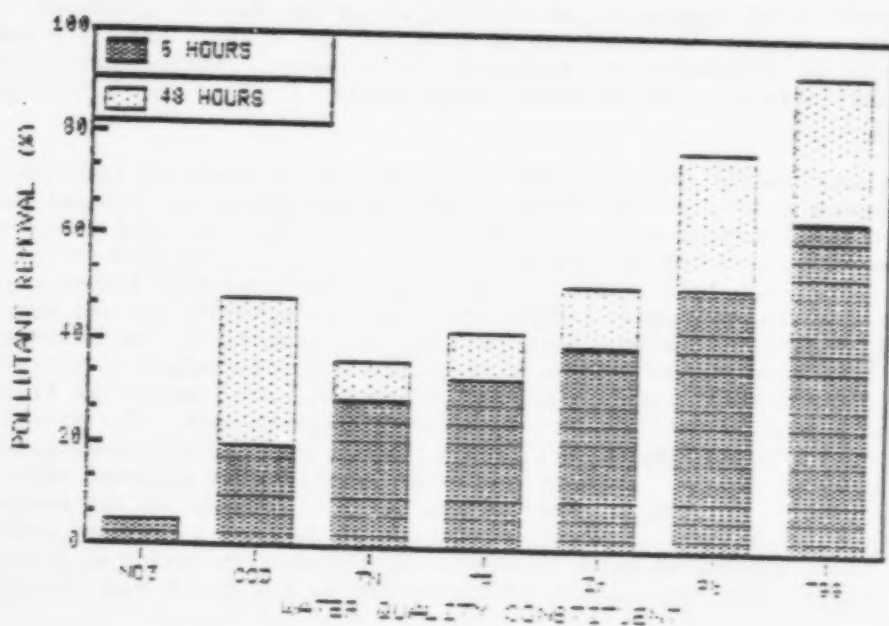


Figure 2.10  
REMOVAL RATES OBSERVED IN EXPERIMENTAL SETTLING COLUMN  
STUDIES: REMOVAL AFTER 6 AND 48 HOURS OF DETENTION



time, and still achieve significant percentage of the long-term sediment removal rate. The same general conclusion apparently holds true for other pollutants, as well. Nearly two-thirds of the maximum removal occurred within the first six hours for nutrients and trace metals (Figure 2.10).

The next phase of analysis attempted to provide information on what maximum settling removal efficiencies might theoretically be for individual water quality parameters. To this end, the settling column data was interpreted in the light of median stormwater runoff concentrations observed in all of the residential and commercial sites monitored in the NURP study. The objective of this analysis was to characterize the removal rate which might be expected for the median urban stormwater runoff event. As a check, these experimental removal rates were compared to the median load removal rates observed at the Stedwick extended detention pond.

The stormwater concentration in settling column experiments which most closely approximated the NURP median urban runoff concentration was identified and the removal rate in that replication after six hours was determined. The six hour settling rate was fortuitous for two reasons. First, the six hour interval was within the range of observed detention times observed at the Stedwick pond. Secondly, regression models applied to the experimental settling data suggested that removal of sediment particles in the 35-45 micron range produced the greatest incremental reductions in associated urban pollutants (OWML, 1983). The time required to settle out these particles within a four foot water column was 5.6 hours.

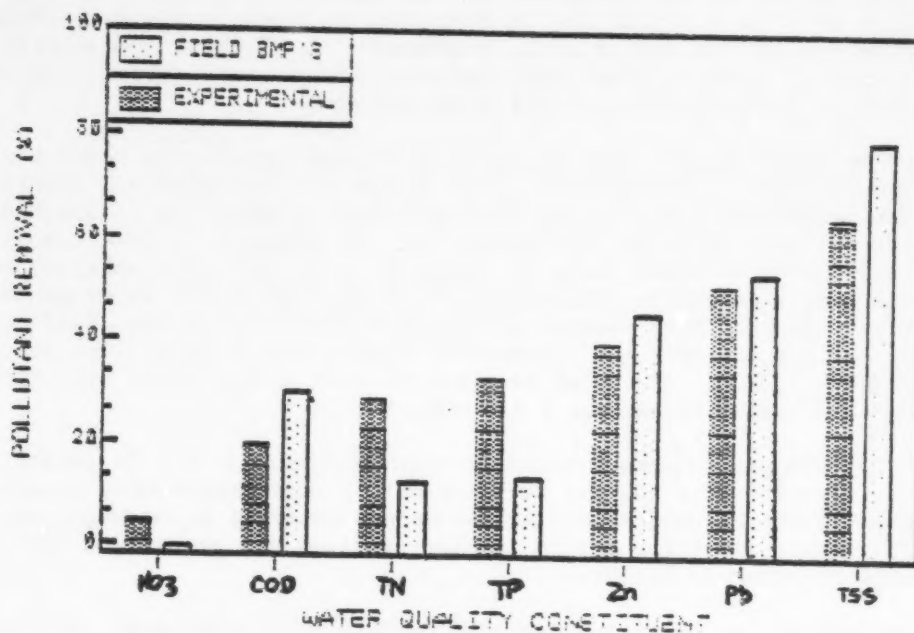
These removal comparisons are illustrated in Figure 2.11. In general, the six hour removal rates for the settling column experiments were in relative agreement with the median loading reductions observed at Stedwick pond. Removal of sediment and trace metals is high, whereas the removal of nutrients and organic matter is slight.

The pollutant settling rates depicted in Figure 2.10 are most instructive. First, there appears to be an upper limit on the amount of removal that can be achieved by settling. In most cases, the greatest proportion of the removal occurs in the first six hours and then declines gradually thereafter. After 12 to 24 hours little, if any, additional removal takes place and a maximum removal threshold is reached. For sediment, this upper threshold of removal is approximately 90 percent. By way of contrast, the maximum removal rate for total nitrogen and phosphorus after 48 hours is only 40 percent. Even a smaller rate is observed for nitrate (10 percent). For COD, the maximum removal after 48 hours approaches 50 percent; while for trace metals the upper threshold of removal is about 50-80 percent. The conclusion which emerges is that if control of nutrient enrichment or oxygen demanding materials is a primary management objective, then other stormwater design features other than extended detention will be required.

## 2. Design of Dry Pond Beds

The contrast in the effectiveness of dry ponds and extended detention ponds observed in this study was dramatic. In many of the storms observed at the dry pond site, removal efficiencies were negligible or negative, indicating the scour and resuspension were recurring problems at the site. On the other hand, the removal rates at the extended detention pond compared favorably to ideal theoretical conditions, implying that scour and resuspension were not influencing the pond's effectiveness. The question that inevitably is raised is why did one pond experience these problems while the other was not affected at all. The answer appears related to the design of the Lake

Figure 2.11  
COMPARATIVE POLLUTANT REMOVAL AFTER SIX HOURS: EXPERIMENTAL  
AND FIELD MEASUREMENTS OF EXTENDED DETENTION



- a. rates derived from six hour data in "Sediment and Particle Size Association Studies". Chapter 11, of OWML (1983)
- b. The median storm was defined the runoff sample used in the settling study which most closely approximated to the median EMC recorded for all residential and commercial sites in the NURP study. This storm (#4) was identical for all quality constituents.
- c. Median loading rate reduction observed in the Stedwick Extended Detention Pond, average detention time 4-6 hours.



Ridge dry pond itself. The pond bed was poorly vegetated and was visibly scoured in several places. By way of contrast the Stedwick extended detention pond had: 1) extensive vegetation; 2) a narrow concrete channel leading into and through the pond; 3) energy dissipating structures which reduced water velocities at the inlet of the pond; 4) a tall riser with a gravel jacket which minimized the likelihood of resuspension of previously deposited materials; and 5) a pond configuration with a high length to width ratio which created ideal settling conditions and avoided problems of "short-circuiting" runoff storage. Incorporation of these design measures is recommended as a means of reducing the potential for detention basins to become a source of nonpoint pollutants.

### 3. Rapid Infiltration/Prolonged Contact Time

Although the performance of infiltration BMPs which were monitored in the NURP study was mixed, a closer scrutiny of the data individual structures and site conditions suggests that infiltration controls can be extremely effective if they are oriented toward: 1) achieving rapid and complete infiltration of stormwater, and 2) maximizing the contact time of stormwater within the soil.

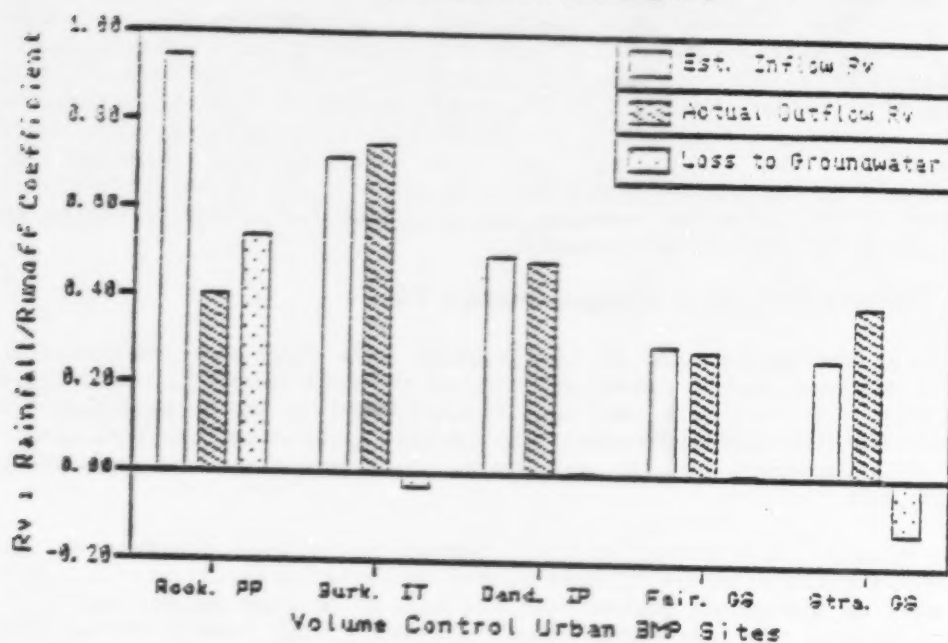
For example, the poorest overall removal rates were observed at the grassed swale sites with the highest slopes and least permeable soils. Presumably most of the runoff passed over the swales, accounting for the mediocre performance. On the other hand, extremely high removal rates were observed at the porous pavement site which had the most rapid infiltration and the largest underground contact time of any of the infiltration structures. This relationship is depicted in Figure 2.12. In this graph, the pollutant removal rate for each structure is plotted against its rainfall/runoff coefficient (which serves as a surrogate measure of the quantity of stormwater which was permanently diverted into the groundwater). A second graph displays the same removal rates compared with the estimated average contact time achieved within the structure itself (Figure 2.13).

### 4. Biological Removal by Pond Ecosystems

Figure 2.14 presents the comparative pollutant removal efficiencies which were observed in the dry pond and pooled wet ponds monitored in the NURP study. As can be seen, the removal rates are significantly higher for most parameters in the wet ponds. Of particular interest is the high removal of soluble nutrient forms which are often responsible for creating eutrophic conditions. While the removal of particulate substances is comparable to those achieved at the Stedwick extended detention Pond (Figure 2.5), indicating that gravity sedimentation alone can account for most of the particulate removal, this additional removal of soluble nutrients is especially noteworthy. The principal removal mechanisms involved appeared to be nutrient uptake by phytoplankton and rooted aquatic vegetation.

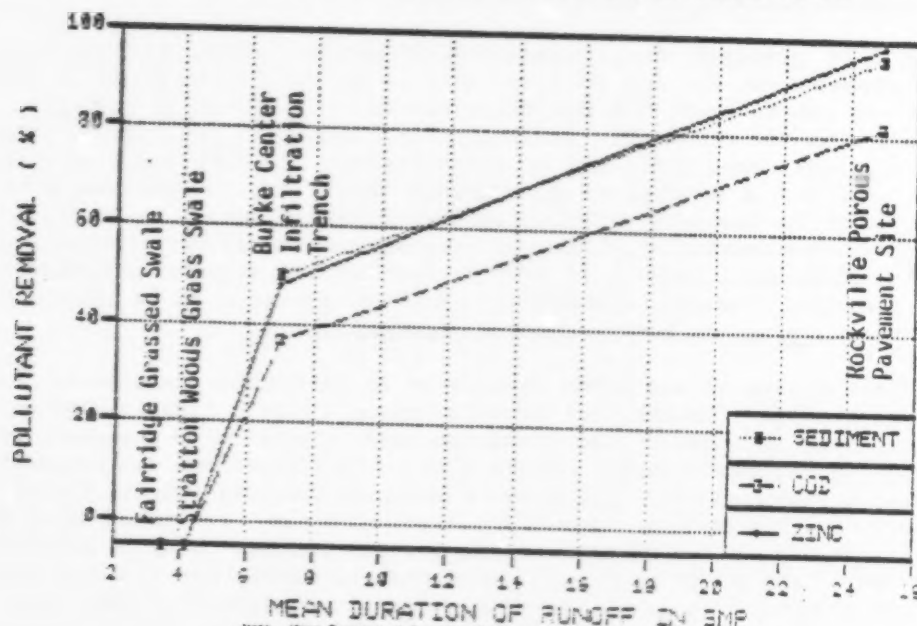
The effectiveness of wet ponds appears to be related to the size of the permanent wet storage. Preliminary data of Driscoll (1983) suggest that removal efficiencies increase as pond areas increase (expressed as a percent of the contributing catchment area - Figure 2.15). This phenomena can probably be attributed to the fact that larger ponds retain pollutants longer, thereby allowing more time for various removal processes to occur. Previous research conducted in the Washington DC area during the 208 process tends to support this assertion. In a study of the pollutant removal capability of a six acre urban lake located below a large shopping center in Montgomery County Maryland, Davis et al (1978) reported pollutant removal rates substantially

Figure 2.12  
ESTIMATED DIVERSIONS TO GROUNDWATER IN SELECTED  
VOLUME CONTROL BMPs



Notes: Estimated inflow Rv values were derived from functional relationships between imperviousness and runoff contained in preliminary assessment of the volume control BMP data base supplied by E.O. Orsini and Associates. Actual Outflow Rv values were determined from on-site comparisons of rainfall and runoff volumes at each BMP site for at least 13 storm runoff events. Inflow Rv - Outflow Rv provides a surrogate measure of the proportion of impervious runoff which was diverted to the groundwater (as opposed to surface runoff). As can be seen, only the Rockville Porous Pavement BMP site experienced these losses. The remainder of the volume control sites had equivalent inflow and outflow water balances.

Figure 2.13  
RELATIONSHIP BETWEEN MEDIAN REMOVAL RATE AND DURATION  
OF RUNOFF WITHIN VOLUME CONTROL BMPs



Notes: Mean Duration of Runoff in BMP was defined and calculated as the over 128 time elapsed between the activation of the on-site removal zone and the termination of the outflow capturing monitor, less seven hours. The seven hours represents the mean storm duration in the watershed - 5 hrs. Orsini, 1983, and a four hour interval of time of concentration. Removal estimates are based on the application of derived 3 median settling rate efficiency, and should be interpreted in the light of previously mentioned limitations in characterizing inflow runoff loads. Any removal efficiencies below zero indicate negative efficiency only. Actual values were not supplied for clarity's sake.

Figure 2.14  
COMPARATIVE PERFORMANCE OF WET AND DRY STORMWATER  
MANAGEMENT PONDS IN WASHINGTON AREA NURP PROJECT

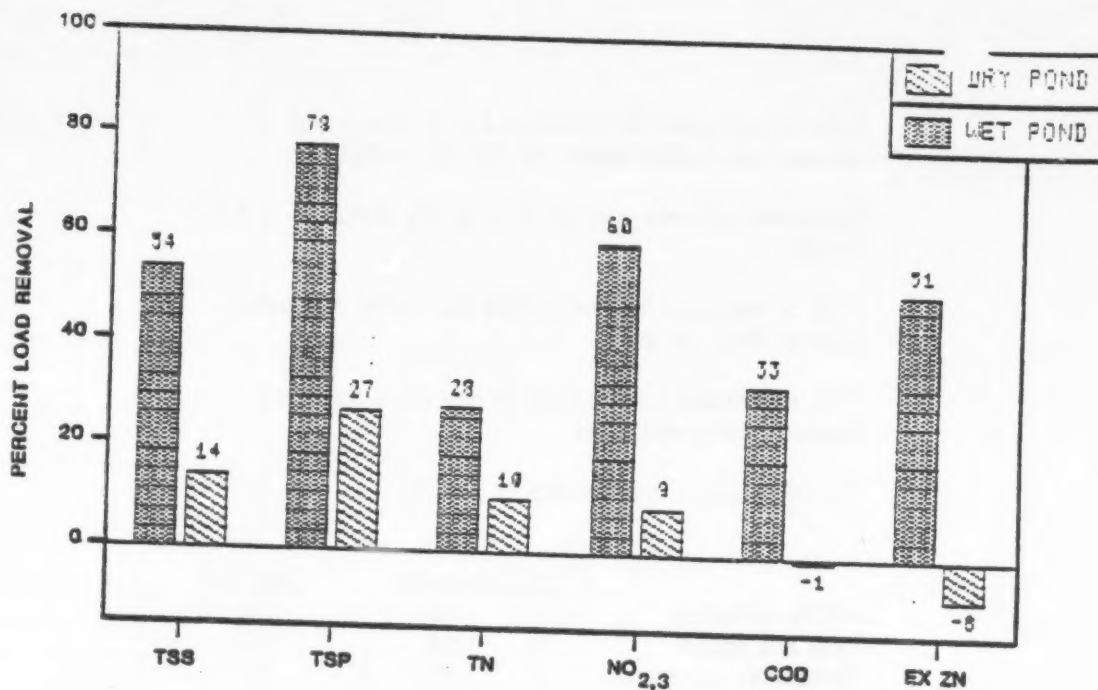


Figure 2.15  
EFFECT OF WET POND AREA ON LONG TERM  
REMOVAL EFFICIENCY

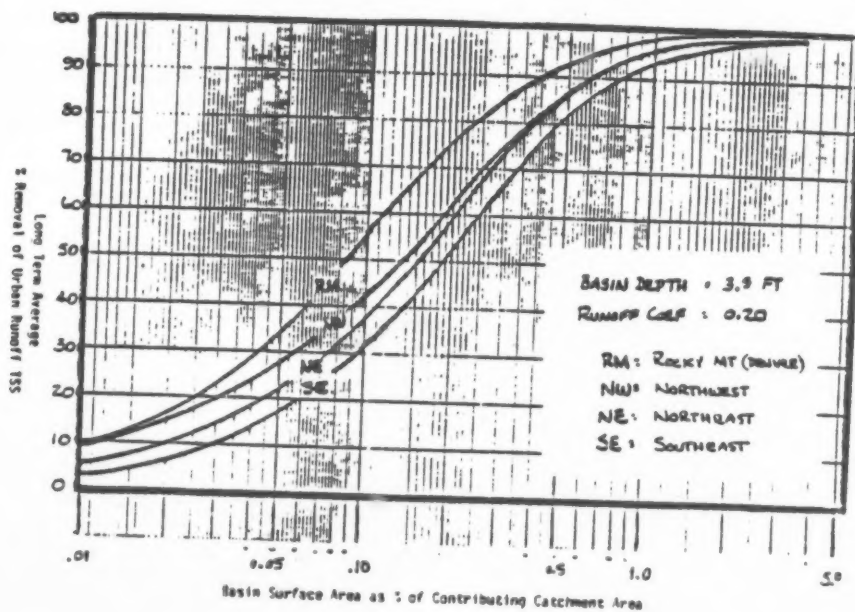


Table 2.14  
CITIZEN ATTITUDES TOWARDS STORMWATER BASINS

94% of residents felt it is desirable to design and manage stormwater basins for fish and wildlife

Residents preferred wet ponds over dry ponds by a 4 to 1 margin

75% of residents felt wet ponds add to the real estate value of their homes

73% expressed a willingness to pay more for home situated near a wet pond

Residents perceived benefits of ponds:

|                        | Wet (%) | Dry (%) |
|------------------------|---------|---------|
| Wildlife attraction    | 65      | 22      |
| Aesthetic appeal       | 58      | 22      |
| Recreation opportunity | 40      | 5       |
| Fishing                | 29      | 0       |

Source: National Institute for Urban Wildlife Resident Attitude Survey, Columbia, MD.  
360 Respondents



higher than those of the NURP wet ponds. The authors concluded that the high removal was due to the 24 to 72 hour detention time of the lake. The long detention time was, in turn, a function of the large capacity of the lake (37 acre feet), and the small size of the outlet.

Besides significantly increasing the degree of nutrient removal from runoff which can be achieved, wet ponds also serve other important purposes. For example, a recent survey of 360 residents in Columbia, Md. (Table 2.14) suggests that the public considers wet ponds to be important resources with respect to wildlife attraction, landscaping, aesthetics, recreation and property values (Adams et al, 1983). A distinct preference for living adjacent to wet ponds rather than dry ponds was also exhibited in this survey. The multi-purpose character of wet ponds, when coupled with their high pollutant removal capabilities suggests that they should be more fully utilized as a stormwater management strategy, rather than relying on the more limited benefits expected from conventional dry ponds.

#### Additional Comments Regarding BMP Efficiency

One of the most fundamental conclusions reached during the Washington area urban BMP effectiveness study is that the pollutant removal behavior of any urban stormwater management practice is extremely complex and variable. While many clearly defined trends were evident in the Washington area database, it is worth noting that each of the 14 BMP sites which were monitored operated in a unique manner, reflecting certain complex site-specific factors. The practical implication, then, is that many factors conspire to influence the pollutant removal behavior of a particular urban BMP, and that each of these factors have to be carefully scrutinized when designing and maintaining a structure to achieve optimal efficiencies. Some of these factors include: 1) the nature and characteristics of the upstream catchment area (e.g., drainage area, land use, soils, loading rates), 2) the quantity of stormwater generated during each storm and the concentration of entrained pollutants, 3) the design criteria of the BMP device (i.e., whether the device effectively regulates runoff from smaller storm events, as well as the 2, 5, 10 or 50 year design storm), 4) the size or storage capacity of the control device relative to its upstream catchment, 5) the actual performance of the device in the field (i.e., does the outlet become clogged, or leak, etc.), and 6) the level of maintenance performed on the BMP over its useful life.

Therefore, the influential effects of these and other factors on the pollutant removal capability of any BMP should be explicitly recognized in the BMP design and site review process.

## CONCLUSIONS AND RECOMMENDATIONS

Six kinds of stormwater management controls in use within the Washington metropolitan area were analyzed to determine their effectiveness in removing pollutants borne in urban runoff. These structures included conventional dry stormwater ponds, extended detention dry ponds, wet stormwater ponds, grassed swales, infiltration trenches and porous pavements. Inflow and outflow from 12 BMP sites was monitored with automated sampling equipment for intervals of 12 to 18 months, and several different estimates of pollutant removal efficiency were computed. The general conclusions concerning the pollutant removal effectiveness of these stormwater controls are as follows:

- Conventional dry stormwater management ponds are not effective in removing the sediments, nutrients, trace metals, or oxygen demanding materials entrained in urban runoff. Stormwater pass through the structure too quickly to achieve significant removal by settling. In some cases, dry ponds can actually become sources of pollutants if the pond bed is not stabilized.
- Extending the detention time of stormwater within dry ponds is a promising technique for removing several common constituents such as sediments, trace metals, and organic nutrients. Removal of biologically available nutrient forms, however, is minimal. This suggests that the extended detention technique will not be useful in areas where control of nutrients is a primary management concern.
- Wet ponds were determined to be an extremely effective urban best management practice. Removal rates for sediment and trace metals were comparable to those observed at the extended detention facility. Also, the biological processes occurring within the pond effectively removed a high proportion of the readily available nutrient forms.
- No statistically significant improvement in either runoff quality and quantity could be demonstrated for grassed swales, when they were compared to their traditional curb and gutter control. The poor performance of the grassed swales appears to be related to the rapid passage of stormwater through the swales.
- Although several methodological and siting constraints limited the usefulness of the infiltration control comparisons, it did appear that these controls tended to be moderately effective in removing sediments, trace metals and oxygen demanding materials, but were generally ineffective in removing soluble nutrient forms and oxygen demanding materials.
- The use of porous pavements proved to be a very effective urban best management with respect to both runoff quality and quantity. High removal rates were noted for nearly all water quality parameters.

During the course of the study, several design concepts emerged as having significant potential for enhancing the pollutant removal capability of stormwater structures. These concepts include:

- Increasing the detention time of stormwaters in pond structures. Evidence presented earlier suggest that 6 to 12 hours of detention is sufficient to achieve about two thirds of the maximum theoretical removal rate. Since removal rates beyond 12 hours occur only in small increments, (and the cost of adding additional storage remains constant) the achievement of extremely long detention times should be carefully examined.
- Pond scour, resuspension, and short-circuiting are all processes which can severely limit the pollutant removal capability of any pond BMP. Therefore, in the design process, special attention should be placed on preventive measures such as revegetation, bank stabilization, energy dissipation, channelization and pond configuration.
- • Infiltration-type BMPs can be extremely effective if they are oriented toward achieving rapid and complete infiltration of stormwater and maximizing the contact time of stormwater within the soil profile. In this respect, infiltration systems should best be designed to retain stormwater within the structure for durations exceeding those suggested for ponds. Design retention times of 24 to 48 hours are frequently recommended because of the smaller storage and through-put of infiltration devices. (Wong, personal communications, September 27, 1983). Even greater performance can be realized if the stormwater is permanently routed into the groundwater pool.
- The multi-purpose character of wet ponds, when coupled with their high pollutant removal capability, strongly suggests that they can be an attractive stormwater management strategy. In general, the pollutant removal efficiency (and presumably the aesthetic, recreational and landscape values, as well), will become greater as pond size increases. Also, the establishment of rooted aquatic vegetation around the periphery of the pond can accentuate pollutant removal as well as attract wildlife. Establishing rooted aquatic vegetation also may have the beneficial effect of diminishing the nutrient supply available to noxious algae during the summer months, thus alleviating a persistent maintenance concern.

## REFERENCES

- Adams, L., L. Dore, D. Leedy and T. Franklin, 1983. Urban Wetlands for Stormwater Control and Wildlife Enhancements Analysis and Evaluation. Urban Wildlife Research Center, Columbia, Maryland. 68 pp.
- Davis, W., L. Williams and D. Bell, 1978. Final Report 208 Project: Onsite Control Measure Study. Prepared for Metropolitan Washington Council of Governments by Montgomery County Department of Environmental Protection. 78 pp.
- Driscoll, E.D., 1983. Performance of Detention Basins for Control of Urban Runoff Quality. Presented at 1983 International Symposium on Urban Hydrology, Hydraulics and Sediment Control. University of Kentucky, Lexington, KY, July 1983. 42 pp.
- Metropolitan Washington Council of Governments (MWCOC), 1980. June 30 Memorandum. Summary of Best Management Practices Monitoring Site Selection Process for Washington NURP. 44 pp.
- \_\_\_\_\_, 1983. Potomac River Water Quality 1982: Conditions and Trends in Metropolitan Washington. Prepared for the Washington Metropolitan Water Resources Planning Board. 107 pp.
- Northern Virginia Planning District Commission (NVPDC), 1980. Guidebook for Screening Urban Nonpoint Pollution Management Strategies. Prepared for MWCOC. 160 pp.
- NVPDC and Virginia Polytechnic Institute and State University (VPI&SU), 1978. Unpublished 208 Single Land Use Watershed Loading Data.
- Northern Virginia Planning District Commission, 1983. Final Contract Report Washington Metropolitan Area Urban Runoff Demonstration Project. Prepared for Metropolitan Washington Council of Governments. 101 pp.
- Oakland, P., 1983. An Evaluation of urban Stormwater Pollution Removal Through Grassed Swale Treatment in Proceedings 1983 International Symposium on Urban Hydrology, Hydraulics and Sediment Control. H. Sterling, editor. University of Kentucky. pp. 183-185
- Occoquan Watershed Monitoring Laboratory (OWML), 1983. Final Contract Report on Metropolitan Washington Urban Runoff Demonstration Project. Prepared for Metropolitan Washington Council of Governments, by Virginia Polytechnic Institute and State University. 350 pp.
- Wong, Stanly. Water Resources Engineer, Water Resources Administration, Maryland Department of Natural Resources. Personal communication. Letter dated September 27, 1983.

Preceding page blank



**CHAPTER THREE**  
**COSTS OF**  
**BEST MANAGEMENT PRACTICES:**  
**STORMWATER MANAGEMENT PONDS**

# CHAPTER III

## COSTS OF BEST MANAGEMENT PRACTICES:

### STORMWATER MANAGEMENT PONDS

#### INTRODUCTION

Local decision-makers involved in stormwater management planning are often faced with choosing from an array of potential runoff control alternatives -- some of them offering similar or equal levels of control -- without having a reasonably accurate idea of the financial impacts or costs of these alternatives. Important considerations in a financial analysis of this kind might include the costs to build the stormwater structure, as well as expenditures over a period of years to provide for maintenance and periodic inspections. One element of the Washington, D.C. NURP project was designed to help local cost-benefit decisions by providing an easily-applied and consistent method of projecting the costs of stormwater management ponds -- now the most widely utilized control practice in the metropolitan area.

This chapter describes COG's pond cost study and suggested approach for projecting total pond construction and maintenance costs over a theoretical 20-year planning period. In general, the study's goal was to present, wherever possible, pond cost estimates that reflected field experience reported by contractors, engineers and public officials involved in stormwater management program implementation.

#### Cost Factors Considered

To develop a full accounting of pond costs, it was felt that several cost factors would need to be computed. These include:

1. Base Construction Costs -- the direct costs to the contractor or implementing agency (exclusive of land costs) to construct a pond at the development site in accordance with typical stormwater management design criteria.
2. Construction-Related Contingency Costs -- the costs associated with administration and oversight during the period of pond design and construction.
3. Pond Operation and Maintenance (O&M) Costs -- the costs to maintain a safe, functioning pond over its useful life or some specified planning period. O&M costs would provide for routine inspections and preventive maintenance performed on a regular basis; non-routine maintenance (such as sediment removal) or repairs to ensure structural integrity; and some allowance for administration of the maintenance program.
4. Long Term Financing -- assignment of a discount rate to factor payments for pond construction and upkeep over a specified planning period.

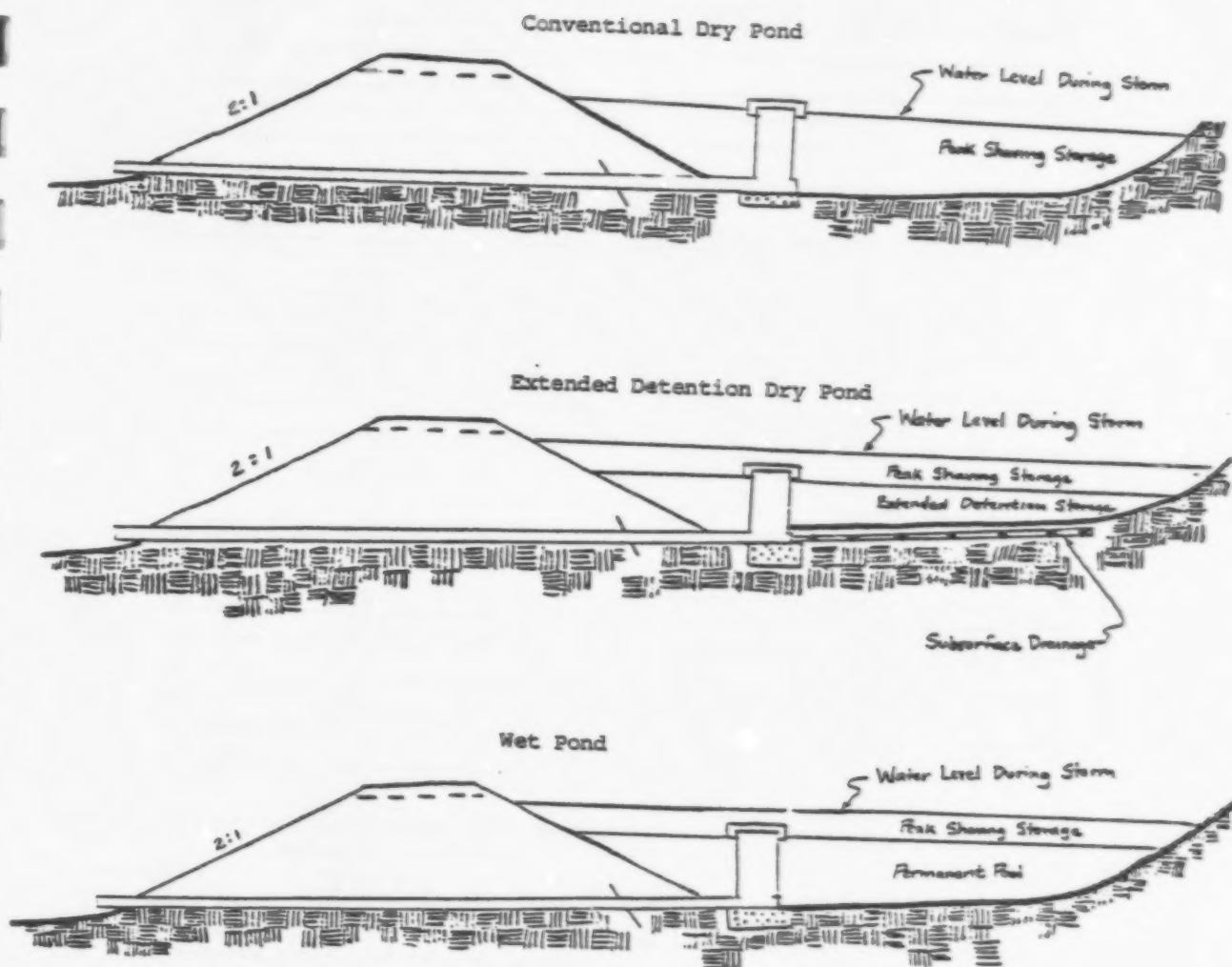
This chapter discusses each of these cost factors as they might be applied to compute total pond costs. The discussion concludes by portraying pond costs on the basis of estimated annual cost to the individual homeowner and commercial property owner.

### Types of Ponds Considered

Three types of stormwater management ponds that are utilized at present locally in conjunction with new residential and commercial development were considered by the study. These are as discussed below and depicted schematically in Figure 3.1. They include:

1. Conventional Dry Pond. Sometimes referred to as a "single-purpose" structure, the conventional dry pond is designed to attenuate peak storm flow from the development site in accordance with specified, predevelopment flow rates. For study purposes, hydrologic design criteria governing peak shaving detention basins in Fairfax County, Va. and Montgomery County, Md. were employed. Typically, the dry pond is designed to detain stormwater for about 2 hours. Local ordinances generally require larger storage volumes as the intensity and size of development increases. The relationship between development category, drainage area, and peak-shaving storage prescribed in Montgomery County is illustrated in Figure 3.2. Montgomery County peak-shaving requirements call for maintenance of post development peak flow from a 2-year design criteria storm at predevelopment levels of approximately 0.6 to 0.8 inches per hour. Fairfax County requires maintenance of post development peak flow from a 10-year design criteria storm at a pre-development level of approximately 0.92 inches per hour.
2. Extended Detention Dry Pond. Introduced in Fairfax County, this dry pond design utilizes the basic peak-shaving storage requirements of a conventional dry pond. The design includes structural modifications to extend the period of stormwater detention and thereby promote physical and chemical removal of runoff pollutants. Design modifications include an additional 15 to 25 percent of storage volume and utilization of subsurface drains to achieve extended detention of up to 40 hours.
3. Permanent Pool Wet Pond. The stormwater management wet pond is designed to maintain a permanent pool of water in addition to supplying the required peak shaving storage. Study estimates employed two different assumptions concerning permanent pool storage. As a first case, it was assumed that the additional a permanent pool area would equal 0.50 inches of runoff storage per acre of drainage (This is the general rule-of-thumb applied for wet pond construction in Montgomery County). For illustrative purposes, a second case was evaluated in which the permanent pool volume equaled the peak-shaving control storage volume.

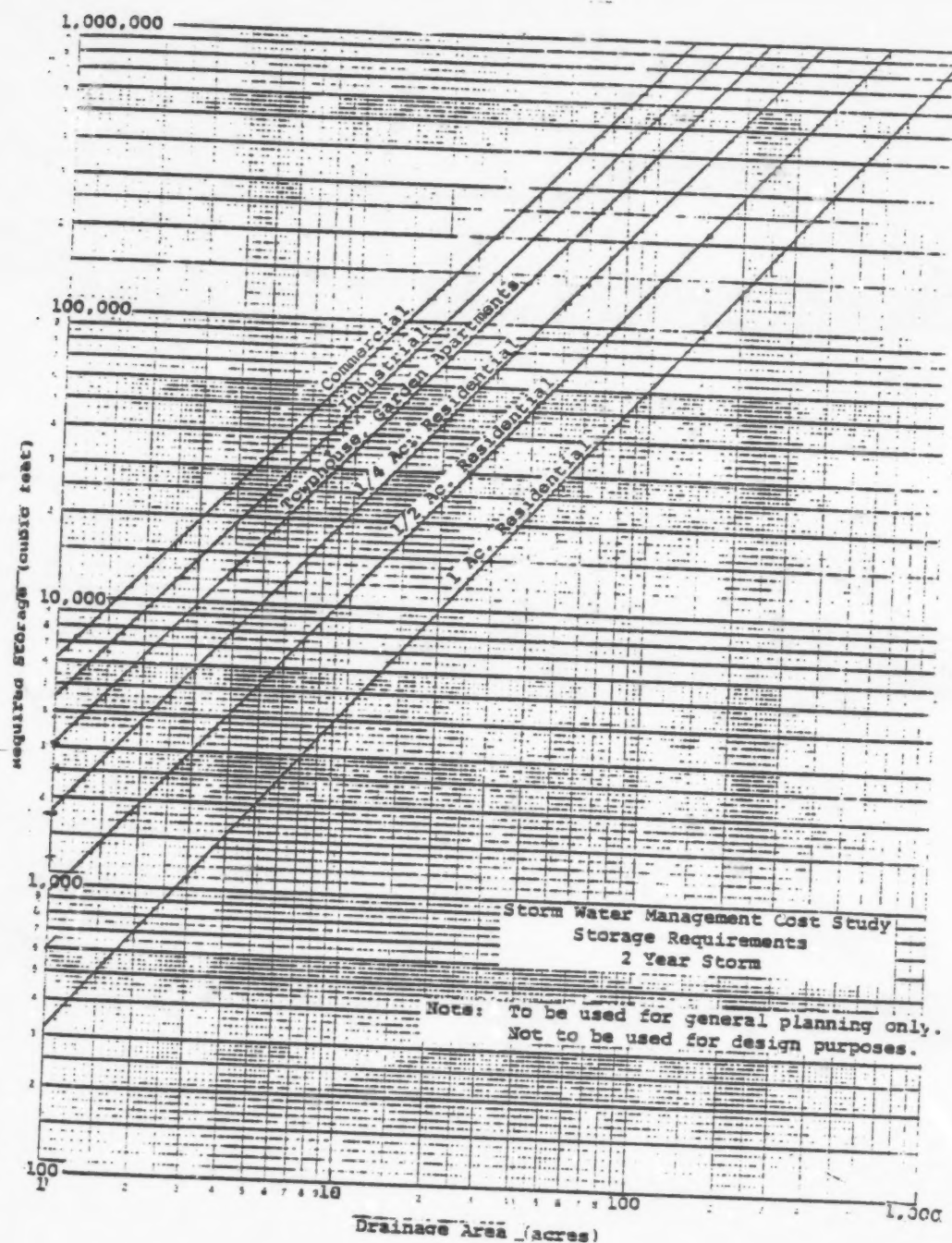
Figure 3.1  
SCHEMMATIC OF STORMWATER MANAGEMENT PONDS



-NO SCALE-



Figure 3.2  
 MONTGOMERY COUNTY STORMWATER POND STORAGE REQUIREMENTS  
 TWO-YEAR DESIGN STORM  
 (DeTullio and Thomas, SCS, 1977)



## METHODOLOGY

This section highlights the study methodology employed to arrive at pond construction and maintenance estimates. A more detailed accounting of the cost study can be found in the COG report, "An Evaluation of the Costs of Stormwater Management Pond Construction and Maintenance Costs," (MWCOCG, June, 1983).

### Base Construction Costs

An earlier pond cost study conducted in Montgomery County, Md. (DeTullio and Thomas, SCS, 1977) discovered a moderately strong non-linear relationship between volume of storage and pond construction costs. To test the validity of this relationship on a more regional basis, the COG study performed statistical analysis on cost data assembled from a survey of private and public sources around the Washington, D.C. metropolitan region. Developed with the assistance of the National Association of Home Builders and Northern Virginia Builders Association, the survey was designed to isolate "unit costs" of various pond components (e.g. excavation, stabilization, anti-seep collars, drains, pipes, trash racks, etc.). These estimates represented "in-place unit costs" (December 1980 dollars), defined as the price of individual components installed at the pond site.

Survey responses from a cross-section of 12 construction engineering firms and public agencies resulted in cost estimates for over 200 separate pond components. Pond site plans and engineering drawings for 31 representative ponds in the region, ranging in size from 2,700 to 740,000 cubic feet of storage, were then evaluated to determine the quantity and sizing requirements of construction components. Unit-cost estimates were applied accordingly to arrive at total construction cost estimates for the 31 ponds. A sample pond cost estimate is shown in Table 3.1. Twelve separate construction cost estimates for each pond, or a total of 372 pond construction estimates, were generated in this manner. General characteristics of the 31 ponds selected for analysis are presented in Table 3.2. Regression analyses were then performed on this dataset to determine the degree of correlation between pond volume of storage ( $V_s$ ) and base construction cost (CC).<sup>1</sup>

Extended Detention Dry Ponds. Design plans for nine dry ponds of the ponds evaluated in the construction cost analysis were modified for cost estimating purposes to incorporate new or revised construction components necessary to achieve greater detention times. Assumed design modifications included increasing the pond storage volume by 19 percent, installation of subsurface drainage, and installation of a non-perforated riser in instances where a riser was not included in the original design plan. In-place unit cost estimates for

<sup>1</sup>Although not evaluated here, land costs are an important factor in establishing the total capital costs of a stormwater management project. For a site-specific analysis, land values are usually known; whereas for a more general, watershed-wide analysis, an average per acre land cost can be assigned for cost estimating purposes. It should be noted that in many instances local government officials involved in sub-division plan review will view the land set aside for the pond area as fulfilling part of the development's "open space" requirements. In this case, the area reserved for the pond may not reduce the developable land within the sub-division.

the modified ponds were then tabulated and resulting pond estimates compared against the average costs of the facility prior to modification.

Wet Ponds. A limited evaluation was performed to determine what additional costs might typically be incurred in wet pond construction as compared to dry pond construction. At the outset, it was assumed that any additional costs would chiefly be a function of the additional storage volume required to achieve a permanent pool of sufficient depth to meet design or aesthetic objectives.

Table 3.1  
SAMPLE ESTIMATE OF POND CONSTRUCTION COSTS  
BASED ON UNIT COSTS  
(180,000 Cu Ft Dry Pond)

| Construction Component                  | Unit Cost (\$)<br>(in place) | Quantity Needed | Total Cost (\$)<br>(Dec. 1980) |
|-----------------------------------------|------------------------------|-----------------|--------------------------------|
| Clearing                                | \$2,729/AC                   | 1.77 AC         | \$4,830                        |
| Clearing and Grubbing                   | 3,293/AC                     | 0.33 AC         | 1,087                          |
| Common Excavation                       | 2.60/AC                      | 2,185 AC        | 5,681                          |
| Hydro Seeding                           | 1,853/AC                     | 1.7 AC          | 3,150                          |
| Compacted Fill                          | 3.30/CY                      | 2185.0 CY       | 7,211                          |
| WSSC Endwall (21")                      | 694/EA                       | 2.0             | 1,388                          |
| Reinforced Concrete Pipe-Class IV (21") | 33/LF                        | 93.0 LF         | 3,069                          |
| Concrete Flume                          | 35/SY                        | 388.0 SY        | 13,580                         |
| Anti-Seep Collar (21")                  | 260/EA                       | 3.0             | 780                            |
| Total Construction Costs                |                              |                 | \$40,776                       |

a/ Unit costs shown in this sample are representative only.

b/ "In-place unit costs" are defined as the price of a pond component installed at the pond site.

MWCOG/12-82

Table 3.2  
CHARACTERISTICS OF PONDS SELECTED FOR COST ANALYSIS

| DRAINAGE                          |                       |                  | AREA                         |                       | CONTROLLED       |                                                           | DRAINAGE AREA         |                  | LAND USE                                                  |                       | POND             |  | STORAGE |  | CAPACITY |  |
|-----------------------------------|-----------------------|------------------|------------------------------|-----------------------|------------------|-----------------------------------------------------------|-----------------------|------------------|-----------------------------------------------------------|-----------------------|------------------|--|---------|--|----------|--|
| On-Site Drainage Category (acres) | Total Number of Ponds | Percent of Total | On-Site Land Use             | Total Number of Ponds | Percent of Total | Volume of Storage (cu ft.) at Crest of Emergency Spillway | Total Number of Ponds | Percent of Total | Volume of Storage (cu ft.) at Crest of Emergency Spillway | Total Number of Ponds | Percent of Total |  |         |  |          |  |
| 1-5                               | 6                     | 26%              | Large Lot Single Family      | 3                     | 10%              | 2,000-10,000                                              | 5                     | 16%              |                                                           |                       |                  |  |         |  |          |  |
| 6-10                              | 5                     | 16%              | Medium Density Single Family | 6                     | 19%              | 10,001-20,000                                             | 4                     | 13%              |                                                           |                       |                  |  |         |  |          |  |
| 11-15                             | 2                     | 6.5%             |                              |                       |                  | 20,001-30,000                                             | 1                     | 3%               |                                                           |                       |                  |  |         |  |          |  |
| 16-20                             | 2                     | 6.5%             |                              |                       |                  | 30,001-40,000                                             | 4                     | 13%              |                                                           |                       |                  |  |         |  |          |  |
| 21-30                             | 1                     | 3%               |                              |                       |                  |                                                           |                       |                  |                                                           |                       |                  |  |         |  |          |  |
| 31-50                             | 4                     | 13%              | Townhouse/Garden Apt.        | 9                     | 29%              | 40,001-50,000                                             | 3                     | 10%              |                                                           |                       |                  |  |         |  |          |  |
| 51-75                             | 4                     | 13%              |                              |                       |                  | 50,001-70,000                                             | 3                     | 10%              |                                                           |                       |                  |  |         |  |          |  |
| 76-100                            | 1                     | 3%               |                              |                       |                  |                                                           |                       |                  |                                                           |                       |                  |  |         |  |          |  |
| 101-150                           | 3                     | 10%              | High Rise Apt.               | 1                     | 3%               | 70,001-100,000                                            | 2                     | 6.5%             |                                                           |                       |                  |  |         |  |          |  |
| 151-200                           | -                     | -                |                              |                       |                  | 100,001-150,000                                           | 5                     | 16%              |                                                           |                       |                  |  |         |  |          |  |
| 201-350                           | 1                     | 3%               | Commercial/Industrial        | 12                    | 39%              | 150,001-200,000                                           | 1                     | 3%               |                                                           |                       |                  |  |         |  |          |  |
|                                   |                       |                  |                              |                       |                  | 200,001-400,000                                           | 1                     | 3%               |                                                           |                       |                  |  |         |  |          |  |
|                                   |                       |                  |                              |                       |                  | 400,001-800,000                                           | 2                     | 6.5%             |                                                           |                       |                  |  |         |  |          |  |
| TOTALS                            | 31                    | 100%             |                              | 31                    | 100%             |                                                           | 31                    | 100%             |                                                           |                       |                  |  |         |  |          |  |

a/Also includes high impervious land uses such as parking lots.



## Contingency-Related Costs

In many instances, contingency costs must be figured into the total pond costs incurred during the planning and design of the stormwater management structure as well as for oversight during construction. No detailed survey of prevailing contingency costs was conducted. However, an allowance equal to 25 percent of base construction cost (CC) appeared to be consistent with the practice used by local governments in the Washington, D.C. area in conjunction with their capital improvement programs. It is also consistent with literature values presented in project management reference books, where suggested values for this purpose ranged from 18 to 31 percent. Accordingly, a factor of 25 percent was assumed in computing total pond construction costs, such that:

$$\text{Total Construction Costs (TC)} = \text{Base Construction Costs (CC)} + 0.25 \text{ CC}$$

## Pond Operation and Maintenance Costs

Facility maintenance is an often neglected aspect of current urban stormwater management programs. Most experts in the field agree, however, that adequate maintenance is essential to ensure that these structures continue to function safely and properly over their useful life. The study sought to develop a method of projecting annual pond operation and maintenance (O&M) costs based on an evaluation of local and national experience in this area. A principal focus of this effort involved identification of commonly experienced O&M tasks and a tabulation of average annual O&M costs on a per structure or per unit basis. Once these O&M costs were determined, they were compared with pond construction costs to see how O&M costs compared as a percentage of base construction costs.

Data collection involved both a review of current literature, as well as direct consultation with private and public sector individuals involved in stormwater management. Approximately 70 phone and letter contacts were made with local individuals and people outside the Washington, D.C. region. Eighteen of those contacted provided written material on O&M tasks and costs. Of these, six provided information of reasonable comparability which lent itself to an analysis of routine maintenance tasks.

The six organizations whose O&M data was utilized are listed in Table 3.3. In aggregate, the data utilized encompassed six separate maintenance programs on a total of 198 ponds. "Maintained acreage" of these ponds (both surface water and surrounding land area) averaged 3.4 acres. The programs observed a fairly extensive range of maintenance activities, including periodic site inspections, removal of floatables and trash, and grass mowing. Reported activities are summarized in Table 3.4. A more complete description of maintenance activities can be found in the COG pond cost report (MWCOC, June, 1983).

Reported program costs were adjusted to a common December 1980 base period utilizing the ENR common labor index for Baltimore, Md (CLI = 342; 1967 = 100).

There appeared to be substantially less documentation available on the costs of non-routine tasks such as sediment removal. Development of these costs required a separate analytical approach (see discussion below).

As a final step, the annual costs assigned to routine O&M were evaluated to see how they compared as a percentage of base pond construction costs.

Table 3.3  
ORGANIZATIONS UTILIZED IN O&M COST ANALYSIS

Local: Washington Metropolitan Area

Department of Parks and Recreation  
City of Rockville, Md.

Parks Department  
Maryland-National Capital Park and Planning Commission,  
Montgomery Co., Md.

Magruder Associates  
Rockville, Md.

Non-Local

Department of Engineering  
City of Sterling Heights, Michigan

Department of Public Works  
City of Troy, Michigan

Waterworks, Waste & Disposal Department  
City of Winnipeg, Canada

---

Sediment Removal. Review of available literature and consultation with local public works officials suggested that costs for non-routine sediment removal operations ranged from \$5 to \$8 per cubic yard of sediment removed, and from \$8 to \$10 per cubic yard for wet pond sediment removal (employing a Dragline Scraper). Next, a determination was made as to how much material might be removed from a pond located in a stabilized development. Sediment accumulation or deposition rates were estimated based on landuse/runoff relationships presented in NVPDC, 1980. For this purpose, a 50 percent sediment trap efficiency was assumed for single purpose dry ponds and 100 percent sediment trap efficiency for wet ponds. Based on these assumptions, a sediment deposition rate of 27 to 78 cubic feet per year was assumed for a dry pond serving 20-acre developments.

Table 3.4  
REPORTED POND MAINTENANCE ACTIVITIES

| MAINTENANCE CATEGORY       | LOCAL WASHINGTON AREA |         |                    | NON-LOCAL               |             |                     |
|----------------------------|-----------------------|---------|--------------------|-------------------------|-------------|---------------------|
|                            | Public                |         | Private            | Public                  |             |                     |
|                            | Rockville,<br>MD.     | M-NCPPC | Magruder<br>Assoc. | Starling Heights,<br>MI | Troy,<br>MI | Winnepeg,<br>Canada |
| <b>ROUTINE</b>             |                       |         |                    |                         |             |                     |
| Site Inspections           | x                     | x       |                    | x                       | x           | x                   |
| Grass Maintenance          | x                     | x       | x                  | x                       | x           | x                   |
| Debris Removal             | x                     | x       | x                  | x                       | x           | x                   |
| Bank Stabilization         | x                     | x       |                    | x                       | x           |                     |
| Weed Control               | x                     |         |                    | x                       | x           | x                   |
| Algae Control              | x                     | x       |                    |                         |             | x                   |
| Insect Control             |                       |         |                    |                         | x           | x                   |
| Forebay Cleaning           | x                     | x       |                    | x                       | x           | x                   |
| Fence Repair               |                       | x       |                    | x                       | x           |                     |
| Program Administration     | x                     | x       |                    | x                       | x           |                     |
| Pump Repair                |                       |         |                    | x                       | x           | x                   |
| Electrical Repair          |                       |         |                    | x                       | x           | x                   |
| <b>NON-ROUTINE</b>         |                       |         |                    |                         |             |                     |
| Sediment Removal           |                       | x       |                    |                         |             |                     |
| Pipe Replacement           |                       | x       |                    |                         |             |                     |
| Regrading                  |                       |         |                    | x                       | x           |                     |
| Access Road<br>Maintenance |                       |         |                    |                         |             | x                   |

MWCOG 12-82

This equates to 270 to 780 cu feet of accumulated material over a ten year period, or approximately 10 to 29 cu yds of material (at 27 cu yd/cu ft). A deposition rate of 54 to 157 cu ft per year was assumed for a wet pond serving the same drainage, equating to 20 to 58 cubic yards of material over a ten year period.<sup>2</sup>

### Long Term Financing

Few jurisdictions and/or private developers have cash-on-hand to pay for a pond immediately, and thus must resort to borrowing to obtain necessary project financing. Financing costs can be considerable, depending on the prevailing rate of interest and the schedule of loan repayment. To account for the effects of financing, pond construction and maintenance cost projections were factored together to identify total annual pond costs that might be anticipated for a pond facility over a 20-year planning period. The combined costs were then amortized over 20 years at an 8 percent discount rate to illustrate the annual schedule of payments over a typical 20 year planning period (See "RESULTS" section for discussion). The calculations used to generate these estimates involved establishing the total present worth of the project (Pc), then multiplying the present worth times a 20 year discount rate factor of 0.1018.

## RESULTS

### Base Construction Costs

Regression analysis of the pond construction costs revealed only a moderately linear correlation between pond cost estimates and the known volume of storage (Pearson R value of 0.70). Nonlinear analysis, on the other hand, yielded a fairly strong correlation with the database, achieving an R value of 0.84. Figure 3.3 illustrates the line of best fit compared against the scatter of construction cost estimates (mean values shown). This line of best fit is expressed by the equation:

$$\text{Base Construction Costs (CC)} = 77.4 \times (V)^{0.51}$$

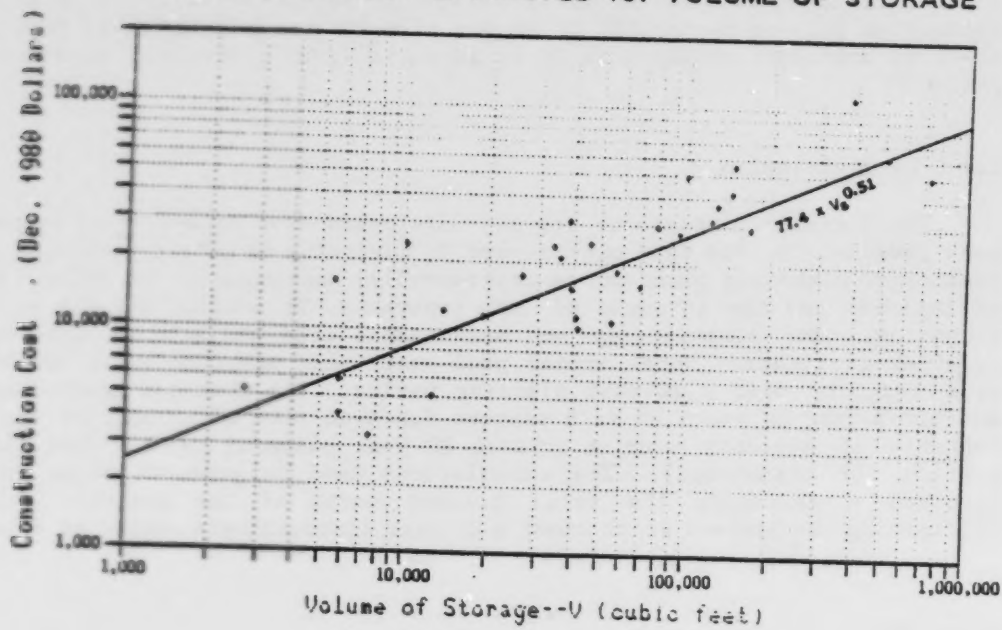
where Vs = design storage volume of the pond up to the crest of the emergency spillway. Figure 3.4 plots the predicted versus observed costs, showing a relationship approaching 1:1. This equation was subsequently selected for use in projecting pond base construction costs for both conventional dry ponds and wet ponds.

---

<sup>2</sup>Sediment and debris accumulation observed over an 18-month period at the Stedwick, Md. extended detention dry pond (see Chapter II discussion) appears to support the assumption of fairly low accumulation rates in stabilized land situations. Deposition rates would be substantially higher in instances where a portion of the pond's drainage area was still undergoing construction, such that the pond was serving as both a sediment catch basin and stormwater control structure.

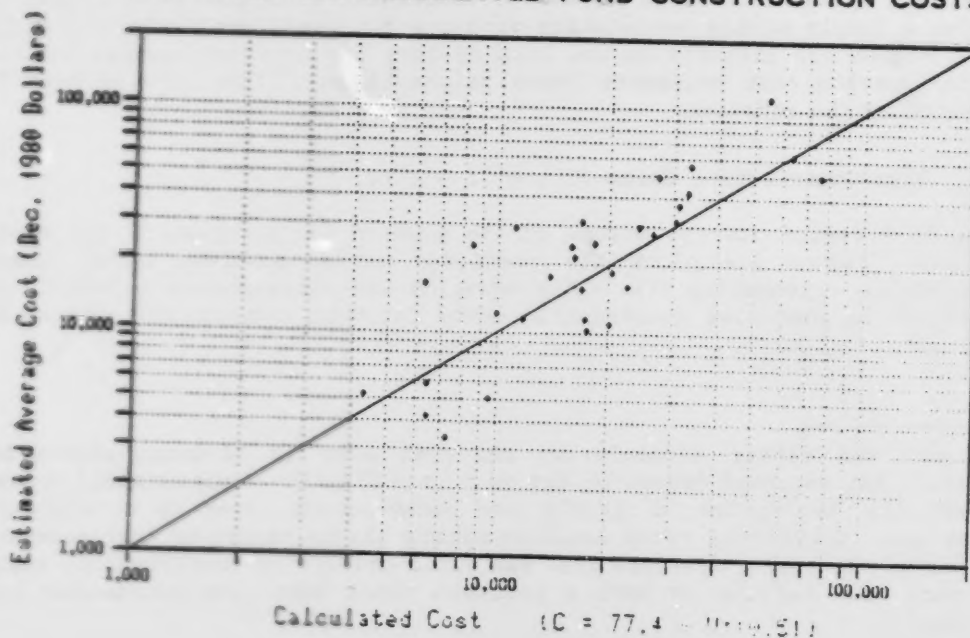


Figure 3.3  
LOG PLOT OF AVERAGE STORMWATER MANAGEMENT POND  
CONSTRUCTION COST ESTIMATES vs. VOLUME OF STORAGE



MMCOG 12-82

Figure 3.4  
OBSERVED vs. CALCULATED POND CONSTRUCTION COSTS



MMCOG 12-82

Employing the predictive equation described above, it was found as expected that construction costs per unit of storage generally decreased with increased pond size. For example, a hypothetical 20,000 cu ft. pond built to control the two-year design storm in Montgomery County shows a cost per unit of storage of about \$0.60 per cubic foot. By comparison, a 60,000 cu ft pond serving a larger drainage area shows unit costs of about \$0.35 per cubic foot.

Table 3.7 and 3.8 estimates indicate that total construction costs per dwelling unit (DU) for 100-acre developments are about 50 percent lower than costs per DU at 20-acre developments.

- For 20-acre developments, dry pond construction costs amounted to about \$230 per dwelling unit (D.U.) for a medium density single family development (4 D.U. per acre), about \$110 per dwelling unit at a townhouse/garden apartment development (10 D.U. per acre), and about \$50 per DU at a high-rise apartment development.
- For ponds serving 100 acre developments, unit costs declined such that dry pond construction amounted to about \$110/DU at a medium density single family development, about \$50/DU at a townhouse/garden apartment site, and about \$23/DU at a high-rise apartment development.

A limited evaluation of several large ponds in Montgomery County indicated that the pattern of decreasing unit costs was not as distinct for ponds exceeding 1,000,000 cubic feet of storage. Presumably the costs to build these larger facilities was driven up sharply by the more stringent structural requirements for major impoundments in urban areas where dam failure could result in safety hazards or damage to residential property. It is also not uncommon to find that construction of larger ponds within a stream valley will require costly realignment of sewer lines, and in some cases, replacement of water mains.

Extended Detention Dry Ponds. Table 3.5 illustrates the results of cost computations for the nine modified dry pond designs that were evaluated and compares these with typical costs prior to modification. As shown, the design modification to achieve extended detention amounted to a 10 to 12 percent increase in base construction costs over dry ponds.

Wet Ponds. A comparison between dry pond and wet pond construction costs showed that wet ponds were more expensive to build than the conventional peak shaving dry pond, due primarily to the additional excavation required to create the permanent pool. To get an idea of the cost differential involved, the cost to volume of storage relationship was utilized to generate a series of estimates according to different land type and sizing assumptions. As mentioned earlier, two different "permanent pool" assumptions were utilized for this purpose. Assuming as a first case a permanent pool area equal to 0.50 inches of runoff storage per acre of drainage, the additional costs were found to range from 26 to 47 percent higher than dry pond construction. Assuming as a second case a permanent pool volume equal to the peak shaving control storage, wet pond costs were estimated to cost approximately 40 percent more than a dry detention basin having comparable peak shaving storage capacity.

Table 3.6 indicates the additional costs of wet pond construction for ponds serving 20 and 100 acre developments. Incremental costs were lowest in high density, impervious developments where a comparatively large peak shaving storage was already required. It should be noted that the allowance utilized in this analysis to account for additional excavation may be excessive and could be less in cases where a development site contains a natural depression in site topography which would facilitate a larger pond without requiring extensive additional excavation.

Table 3.5  
INCREMENTAL COSTS OF MODIFIED DETENTION POND CONSTRUCTION

| POND              | ESTIMATED CONSTRUCTION COST<br>(1980 dollars) |          | INCREMENTAL<br>COST INCREASE<br>(%) |
|-------------------|-----------------------------------------------|----------|-------------------------------------|
|                   | Peak-Shaving Facility                         | BMP      |                                     |
| 1                 | \$23,044                                      | \$25,493 | 11                                  |
| 2                 | 27,965                                        | 29,336   | 5                                   |
| 3                 | 12,922                                        | 15,609   | 21                                  |
| 4                 | 34,589                                        | 38,152   | 10                                  |
| 5                 | 6,311                                         | 8,062    | 28                                  |
| 6                 | 5,194                                         | 6,427    | 24                                  |
| 7                 | 38,973                                        | 39,844   | 2                                   |
| 8                 | 53,316                                        | 54,305   | 6                                   |
| 9                 | 22,291                                        | 23,056   | 3                                   |
| Mean % Increase   |                                               |          | 12.2                                |
| Median % Increase |                                               |          | 10.0                                |

MWCOG 12-82

Table 3.6  
COMPARISON OF WET vs. DRY POND CONSTRUCTION COSTS (a)

| Land Use                                                                   | Peak-Shaving<br>Storage (b)<br>cubic feet | Permanent<br>Pool Area<br>cubic feet | Total<br>Wet Pond<br>Costs (a) | Percent Cost<br>Increase<br>Attributed to<br>Permanent<br>Pool Storage |
|----------------------------------------------------------------------------|-------------------------------------------|--------------------------------------|--------------------------------|------------------------------------------------------------------------|
| 20-Acre<br>Medium<br>Density<br>Single<br>Family<br>(25% imper-<br>vious)  | 32,000                                    | 36,300                               | \$22,610                       | 47%                                                                    |
| 20-Acre<br>Townhouse-<br>Garden Apt.<br>(40% imper-<br>vious)              | 56,000                                    | 36,000                               | 26,300                         | 29%                                                                    |
| 100-Acre<br>Medium<br>Density<br>Single<br>Family<br>(40% imper-<br>vious) | 180,000                                   | 181,500                              | 52,900                         | 43%                                                                    |
| 100-Acre<br>Townhouse-<br>Garden Apt.<br>(40% imper-<br>vious)             | 310,000                                   | 181,500                              | 61,900                         | 26%                                                                    |

(a) Base Construction Costs, based on COG  
volume storage-construction cost projections (1980 dollars).  
Rounded to nearest hundred dollars.

(b) Montgomery County peak shaving requirements for maintenance  
of 2-year design criteria storm at predevelopment levels  
of approximately 0.6 to 0.8 inches/hour. Permanent pool  
area based on 0.30 inches runoff storage per acre of drainage.

MWCOG, 6-83



## Pond Operation and Maintenance

### Routine Maintenance Activities

Table 3.4 lists the maintenance activities reported by the six information sources. These activities generally fell into one of two categories: 1. "Routine" maintenance tasks performed on some regular basis during the year and generally viewed as preventive in nature and 2. "Non-routine" maintenance tasks (performed once over a specified period of years) that involve correction of structural problems or removal of long term accumulations of sediment and debris. Information provided by the six organizations permitted calculation of O&M costs covering routine maintenance activities. Average annual routine O&M was calculated at \$286 per maintained acre, and \$982 per pond structure. Grass mowing and minor debris removal accounted for most of this yearly O&M expenditure. The O&M cost values of \$286/maintained acre and \$982/pond were compared to a representative sampling of 16 of the 31 ponds evaluated in the construction cost analysis. At \$286 per maintained acre, routine O&M was seen to represent about 1.3 percent of the average base pond construction costs. On a cost per structure basis, the \$982 per pond estimate was seen to represent about 2.8 percent of base construction costs.

### Non-Routine Sediment Removal

Employing the assumption made above concerning sediment accumulation and the per unit sediment removal costs, the cost of a 10-year non-routine clean-out operation, translated to an annual basis, represented about 0.2 to 0.75 percent of the base construction cost of a dry or wet pond draining a 20-acre watershed. With an allowance of an additional 25 percent to cover administration and other contingencies, a value of 1 percent of base construction costs was estimated for purposes of estimating non-routine pond O&M.

In instances where off-site hauling distances are great and disposal charges are expected, an allowance of 2 percent was believed appropriate. The 1 to 2 percent projection appeared to also hold true for larger drainage areas up to 100 acres.<sup>3</sup>

When cost projections for routine maintenance activities as well as for non-routine sediment removal are combined, application of 3 to 5 percent of estimated base pond construction costs appeared to be a reasonably conservative, planning-level approach to projecting annual O&M costs. For the analysis presented here, the latter value was used, such that:

$$\text{O\&M} = 0.05 \text{ CC}$$

<sup>3</sup>Although a 10-year clean-out cycle was calculated for non-routine maintenance, wet ponds may require less frequent clean-out (on the order of once every 20 years), if the volume of "dead storage" in the permanent pool is substantial. This would reduce the overall maintenance costs associated with wet ponds.

### Computation of Total Annual Pond Costs

Total annual pond costs on a dwelling unit basis help portray the financial commitment associated with pond construction and upkeep over a typical 20-year planning period. The following discussion provides an example for readers of the computation steps utilized to project total pond costs over a 20-year planning period. This example assumes a 26,862 cubic foot dry pond built according to Fairfax County design criteria, capturing runoff from a 20-acre medium density single family subdivision (4 dwelling units-DU- per acre; 80 DU per 20 acres). Total annual pond costs would be computed as follows:

$$\begin{aligned}(1) \text{ Base Construction Costs (CC)} &= 77.4 (Vs)^{0.51} \\ &= 77.4 (26,862)^{0.51} \\ &= \$14,048\end{aligned}$$

$$\begin{aligned}(2) \text{ Total Construction Costs (TC)} &= CC + 0.25 (CC) \\ &= \$14,048 + \$3,512 \\ &= \$17,560\end{aligned}$$

$$\begin{aligned}(3) \text{ Annual Operation and Maintenance (O\&M)} &= 0.05 (CC) \\ &= 0.05 (\$14,048) \\ &= \$702 (\text{per year})\end{aligned}$$

$$\begin{aligned}(4) \text{ Total Present Worth (Pc)} &= TC + O\&Mp \\ &\text{(factored for 20 years at 8\%)}\end{aligned}$$

where O&Mp equals O&M x 9.818,  
such that

$$\begin{aligned}Pc &= \$17,560 + \$6,892 \\ &= \$24,452\end{aligned}$$

$$\begin{aligned}(5) \text{ Equivalent Annual Payment (Ap20)} &= Pc \times 0.1018 \\ &\text{(20 years at 8\%)} \\ &= \$2,489 (\text{per year})\end{aligned}$$

$$\begin{aligned}(6) \text{ Equivalent Annual Payment per Dwelling Unit} &= \$2,489 \div 80 \text{ DU} \\ &= \$31\end{aligned}$$

In similar manner, cost comparisons were prepared for dry ponds serving hypothetical 20 acre and 100 acre drainage areas (see Tables 3.7 and 3.8). Resulting estimates suggest that significant economies of scale can be achieved by building larger ponds to serve a greater portion of a residential or commercial development. Looking at total pond project costs (construction and O&M) extended over a 20-year planning period, annual pond costs per dwelling unit for a pond serving a 20-acre development were estimated at about \$32/D.U./year (medium density single family development) and approximately \$16/D.U./year at a townhouse/garden apartment development.

Total annual costs are also portrayed in Figure 3.5 (a,b), which compares the cost of three different pond types serving identical 20-acre land uses. As

3.18

USA - Not Applicable.  
An eleven county peak sharing delineation basin design requires maintenance of peak development peak flow from a 10-year Lafayette County based criteria storm at a predevelopment level of approx. 0.85 cfs/acre.  
Based on 10 ft of estimated construction costs.  
Costs per acre.  
Rounded to nearest whole dollar.

10/1 1997

**Table 3.8**  
**PROJECTED CONSTRUCTION AND MAINTENANCE COSTS**  
**OF DRY DETENTION PONDS**  
**- 20 and 100 Acre Developments -**  
**Montgomery County 2-Year Design Criteria (a)**

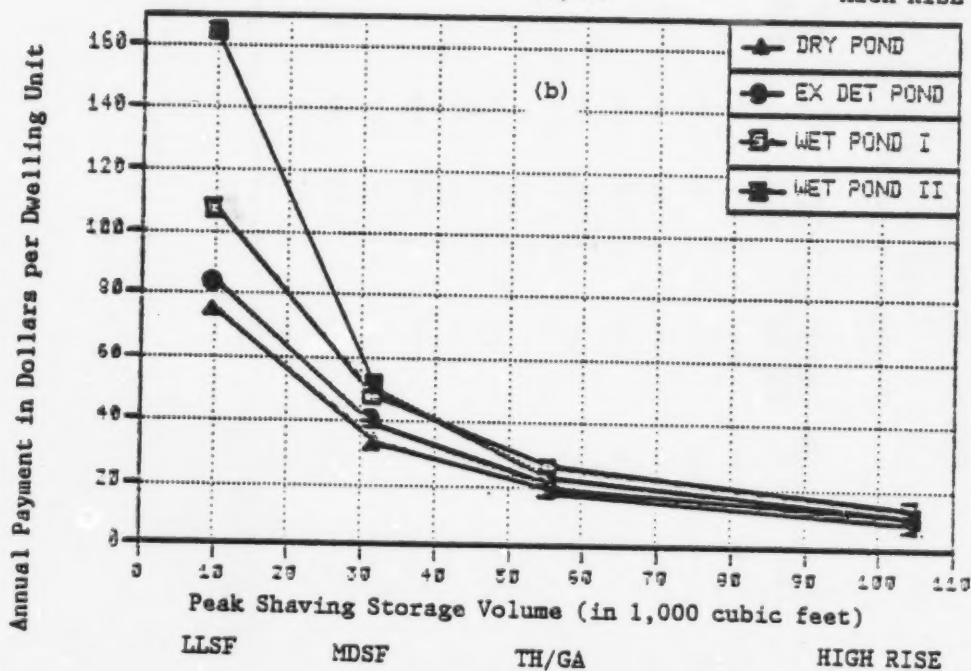
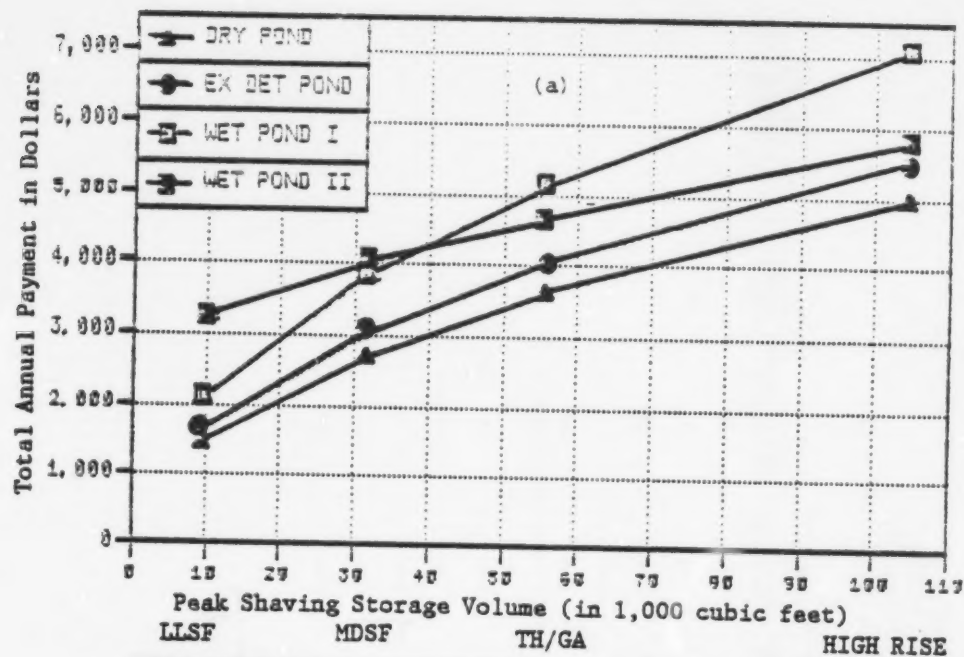
[illegible]

1

**W/O - Not applicable**  
**Assessment** - The assessment with shared detention basis requires maintenance of post-development peak flow from a 2-year Montgomery County design storm. The post-development peak flow shall be 0.5 to 0.6 cfs/acre.  
**Design** - The design shall be based on 50 ft of estimated detention costs.  
**Costs per acre**  
 Estimated to be \$100,000 to \$150,000 per acre.  
 Rounded to nearest whole dollar.



**COMPARATIVE TOTAL COSTS FOR DIFFERENT PONDS IN  
RELATION TO LAND USE DENSITY SERVICED**  
- Dry Pond, Extended Detention Dry Pond, Wet Pond -



**KEY** DRY POND = conventional dry pond  
 EX DET POND = extended detention dry pond  
 WET POND I = permanent pool equal to peak shaving storage volume  
 WET POND II = permanent pool equal to 0.50 inches runoff storage per acre drainage

LLSF = Large Lot Single Family (1 dwelling unit - DU - per acre)  
 MDSF = Medium Density Single Family (4 DU per acre)  
 TH/GA = Townhouse/Garden Apartment (10 DU per acre)  
 HIGH RISE = High Rise Apartment (30 DU per acre)

MWCOG 10-83

can be expected, wet ponds and extended detention dry ponds involve higher total annual costs at each of the residential developments considered (Fig. 3.5 a). The cost differential between pond type is far less pronounced at higher density land uses when evaluated on the basis of annual cost or payment per dwelling unit (Fig. 3.5 b). In the case of the townhouse/garden apartment or high-rise development, this is in part a function of the annual costs being divided among a larger population served by the pond. The economies of scale achieved in higher density areas thus may weigh in favor of wet pond or extended dry pond construction, despite their additional costs.

Annual pond costs are lower for ponds serving 100-acre developments, with costs estimated at about \$10/D.U./year for a medium density single family development and \$5/D.U./year at a townhouse/garden apartment development.

## CONCLUSIONS

### Construction Costs

Regression analysis of unit cost data applied to 31 representative Washington area dry and wet ponds (ranging in size from 2,700 to 740,000 cubic feet of storage) revealed that a pond's computed volume of storage could be used as a planning level approach to predict the pond's construction costs. The principal relationship can be expressed by the equation:

$$\text{Base Construction Cost (CC)} = 77.4 \times V_s^{0.51}$$

where  $V_s$  equals the volume of storage up to the crest of the emergency spillway. In the case of wet ponds, an extra increment of storage volume would be assumed to account for the presence of the permanent pool.

An allowance equal to 25 percent of base construction cost was considered to be appropriate to account for costs incurred during the planning and design of the pond structure. Thus,

$$\text{Construction-Related Contingencies (c)} = 0.25 \text{ CC}$$

and

$$\text{Total Construction-Related Costs (TC)} = \text{CC} + c$$

An evaluation of construction estimates for a variety of pond sizes suggested that construction costs per unit of storage generally decreased with increased pond size. This suggests that certain economies could be achieved by constructing larger ponds which serve a larger portion of the drainage area as opposed to construction of several smaller ponds. These marginal unit cost benefits do not appear to be as distinct for construction of larger ponds in excess of 1,000,000 cu ft.

Extended Detention Dry Ponds. Modification to design criteria of conventional peak-shaving dry detention ponds to achieve longer detention times and higher levels of pollutant removal were estimated to involve about a 10 to 12 percent increase in dry pond construction costs.

Wet Ponds. Cost comparisons between wet ponds and dry ponds indicated that wet ponds cost some 26 to 46 percent more than single purpose dry pond construction, primarily because of the extra pond volume required to achieve the permanent pool area. Several factors may weigh in favor of wet pond construction despite these additional costs, including the exceptional pollutant removal characteristics of wet ponds, and instances where site topography can accommodate the additional pond volume without substantial additional excavation.

### Pond Operation and Maintenance Costs

Another component of total pond costs are the expenditures involved in the operation and maintenance (O&M) of the pond over its useful life. Typical O&M activities include a number of preventive and corrective tasks such as inspections, grass mowing, debris removal, bank stabilization, nuisance control, and removal and disposal of accumulated sediments on a 10 to 20-year basis. Information assembled on maintenance practices experienced in the Washington region and elsewhere in the U.S. appears to support the practice of utilizing 5 percent of base construction costs as a realistic and fairly conservative "rule of thumb" estimate for projecting O&M costs for these structures. Wet ponds and extended detention dry ponds do not appear to require more maintenance than that assigned to conventional dry ponds. There is some indication that wet ponds that have considerable permanent pool volume may require less frequent sediment removal, which would reduce overall maintenance costs.

### Total Annual Pond Costs

Total annual pond costs on a dwelling unit basis help portray the financial commitment associated with pond construction and upkeep over a typical 20-year planning period. Annual costs for conventional dry ponds serving a 20-acre development were estimated at about \$32 per dwelling unit (DU) at a medium density single family development, and at about \$16 per DU at a townhouse/garden apartment development. Estimated annual costs show a pattern of decreasing costs per unit of storage in instances where a larger pond is constructed to serve a larger drainage area. For example, annual costs for a conventional dry pond serving 100-acre developments were estimated at \$10 per DU (medium density single family development) and \$5 per DU at a townhouse/garden apartment development. By way of comparison, the average annual Washington, D.C. area sewer bill in 1982 has been estimated at \$123 per household (MWCOC, August, 1983).

Although the annual payment for extended detention dry ponds and wet ponds is greater than that estimated for a conventional dry pond, the cost differences pond types appears to be far<sup>less</sup> substantial (on a dwelling unit basis) when the ponds are employed to control runoff from higher density developments.

## REFERENCES

- American Public Works Association, 1981. Urban Stormwater Management: Special Report No. 49, Chicago, Illinois.
- Clough, Richard H., 1972. Construction Project Management, John Wiley & Sons, Inc., New York.
- Dean, Lillian F., 1981. Effective Stormwater Management Programs: Case Studies of Local Government Experiences in Southeast Michigan, prepared for the Southeast Michigan Council of Governments, March.
- DeTullio, David and Thomas, Roger, July 1977. Stormwater Management Cost Study, USDA Soil Conservation Service, for Maryland-National Capital Park and Planning Commission, July.
- Dow Chemical Company, February, 1972. An Economic Analysis of Erosion and Sediment Control Methods for Watersheds Undergoing Urbanization (C-1677), Final Report, prepared for U.S.D.I., Washington, D.C.
- Fairfax County, Department of Environmental Management, 1980. Design Manual for BMP Facilities.
- Gannett Fleming Corddry and Carpenter, Inc., March, 1975. Crabbs Branch Storm Water Management Study, prepared for the Montgomery County Department of Environmental Protection.
- Lynard, William G. et al., Metcalf and Eddy, August, 1980. Urban Stormwater Management and Technology: Case Histories, prepared for U.S. Environmental Protection Agency, Office of Research and Development, Cincinnati, Ohio.
- Marks, Raymond A. 1978. "Maintenance Cost Impact, P.L. 566 Dams, Storm Detention Facilities", Fairfax County Department of Public Works.
- Maryland Water Resources Administration et al. 1974. Joint Construction Sediment Control Project, prepared for U.S. Environmental Protection Agency, Office of Research and Technology, Washington, D.C., April.
- Maryland Department of Water Resources et al. 1972. Guidelines for Erosion and Sediment Control, Planning and Implementation, prepared for the U.S. Environmental Protection Agency, Office of Research and Monitoring, Washington, D.C., August.
- Metropolitan Washington Council of Governments, August 1983. Potomac River Water Quality 1982: Conditions and Trends in Metropolitan Washington, prepared for Water Resources Planning Board.
- Montgomery County Department of Environmental Protection, 1978. Final Report, Project 208 On-Site Control Measure Study, prepared for the Metropolitan Washington Council of Governments.



- Montgomery County Stormwater Management Financing Committee, Montgomery County Council, April 1979. "Report of the Storm Water Management Projects Financing Committee".
- Northern Virginia Planning District Commission, April 1980. Guidebook for Screening Urban Nonpoint Pollution Management Strategies, prepared for the Metropolitan Washington Council of Governments.
- Rawls, Walter J. and Knapp, John W. September, 1972. "Methods for Predicting Urban Drainage Costs, Journal of the Hydraulic Division, ASCE."
- Rawls, Walter J. and McCuen, Richard H., November, 1978. "Economic Assessment of Storm Drainage Planning," Journal of the Water Resources Planning and Management Division, ASCE.
- Rockville, City of. December, 1982. "Proposed Revisions to Chapter 17 (grading, erosion and sediment control ordinance).
- Southeast Michigan Council of Governments 1981. "Detention Basin Maintenance: Program Needs and Financing Options".
- Tourbier, J., Toby and Westmacott, Richard. 1981. A Handbook of Measures to Protect Water Resources in Land Development, Urban Land Institute, Washington, D.C.
- U.S. Environmental Protection Agency, Office of Water Program Operations, July 1973. "Comparative Costs of Erosion and Sediment Control, Construction Activities, Washington, D.C.
- Urban Land Institute, American Society of Civil Engineers, National Association of Home Builders, 1975. Residential Storm Water Management: Objectives, Principles, and Design Considerations.
- Winnebago County Public Works Department, August 1976-February 1978. "Detention Practice Under the Storm Water Detention Ordinance of Winnebago County, Illinois.
- Wiswall, Kenneth C. and Shumate, K.S. April, 1976. Stormwater Management Design: A Manual of Procedures and Guidelines, prepared for Maryland Department of Natural Resources by Roy F. Weston, Inc., West Chester, Pa.

**CHAPTER FOUR**  
**ATMOSPHERIC LOADING STUDIES**

## CHAPTER IV

### ATMOSPHERIC LOADING SOURCES

#### INTRODUCTION

This chapter presents the major findings and conclusions of the atmospheric source monitoring field studies conducted as part of the overall Washington NURP project. These monitoring efforts included the operation of the four wetfall/dryfall samplers and the chemical analysis of Total Suspended Particulates (TSP) filter mats collected from eight regional high volume air quality samplers. The primary objective of these monitoring efforts was to characterize the nature, magnitude and variability of atmospheric deposition processes within the region, and to define their relative influence on the quality of urban runoff.

#### Interactions Between Air and Water Quality Processes

Figure 4.1 presents a simplified representation of some of the interrelationships of air and water quality processes. As can be seen, pollutants are contributed to the atmosphere by a variety of sources, including local point and mobile sources (e.g., utility stacks and motor vehicles), local fugitive emissions (such as street dust and wind-eroded materials) and transport from non-local areas. Collectively, these emissions, composed of gases, aerosols, and particulates, become entrained within the atmosphere, and are subject to a complex series of chemical reactions and transformations.

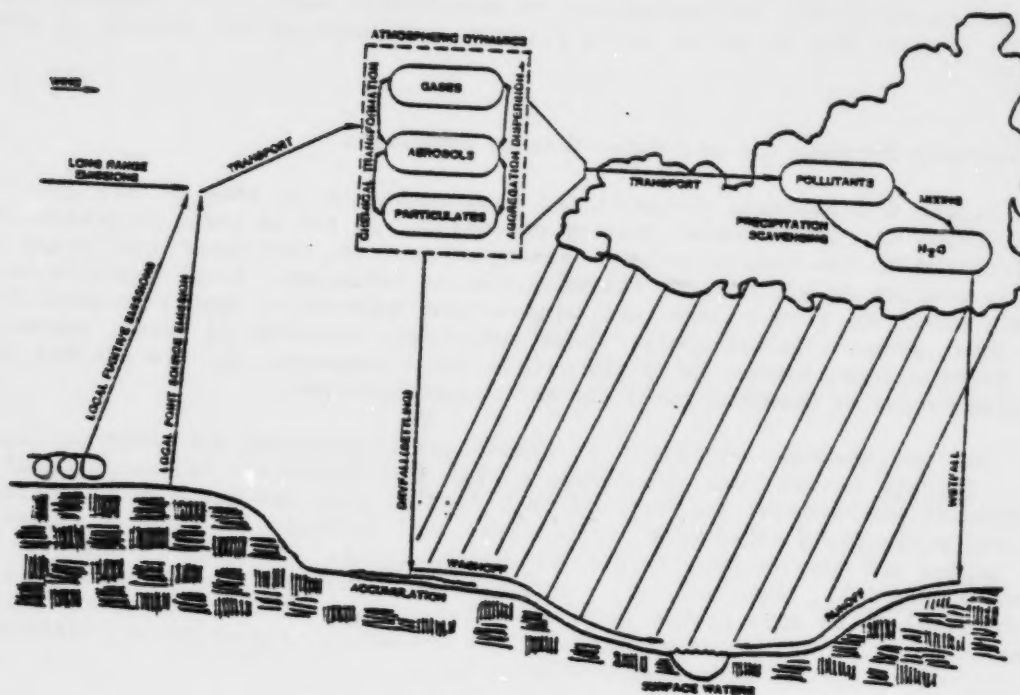
The two dominant pathways for atmospheric deposition are shown in Figure 4.1. Dryfall occurs when turbulence within the atmosphere is insufficient to counteract the natural tendency of particles to fall out (at a rate governed, but not exclusively determined, by gravitational forces). As might be expected, the larger and heavier particulates settle out first. The second deposition mechanism, wetfall, involves the adsorption and condensation of pollutants to water droplets or snow flakes (a process referred to as scavenging) and subsequent deposition with precipitation. This mechanism is particularly effective at delivering gas and aerosol particles.

As atmospheric pollutants settle out, they can exert influence on surface waters in several ways. Pollutants contained in wetfall can be directly conveyed by runoff, whereas the accumulated dryfall pollutants can be washed off the land surface. In both cases, the total atmospheric load actually delivered to streams is strongly influenced by the characteristics of the land surface. In general, greater delivery of atmospheric pollutants is achieved on impervious areas. Other dynamic factors which control the rate of atmospheric deposition include the magnitude and proximity of emission sources, wind speed and direction, and precipitation frequency.

#### Issues Addressed in the Atmospheric Source Study

The overall monitoring program involved both the measurement of the chemical composition of the atmosphere and deposition rates at the land surface, and was directly paired with the measurement of pollutant loading in urban runoff. By using this integrated approach, it was felt that the sampling program could provide a better understanding of the complicated interrelationship between air

Figure 4.1  
SIMPLIFIED REPRESENTATION OF THE DYNAMIC INTERACTION  
OF AIR AND WATER QUALITY PROCESSES





and water quality systems. Several of the specific research objectives are described below:

1. To establish the magnitude of atmospheric deposition within the Washington metropolitan area.
2. To define the relative importance of the dryfall and wetfall pathways.
3. To determine if atmospheric deposition rates exhibit any broad seasonal or geographical trends.
4. To discover if the trends in deposition rates can be related to the composition and concentration of the overlying air mass.
5. To establish the pH of rainfall in the region, and to explore potential effects.
6. To relate atmospheric loading rates to urban runoff loading rates.
7. To identify major sources of atmospheric deposition.
8. To investigate the possibility that multiple air and water quality benefits could be achieved through source control.

Following a brief description of the characteristics of the atmospheric monitoring study, the major findings concerning each objective will be presented.

## METHODS FOR MONITORING ATMOSPHERIC SOURCES

### Atmospheric Deposition Measurements

Atmospheric deposition rates were monitored using model 301 Aerochem Metrics wetfall/dryfall monitors. These monitors allowed for automatic collection and segregation of wet and dryfall samples in acidwashed poly-propylene buckets. During intervals of dry weather, the dryfall collecting bucket was exposed to the atmosphere, while a "roof" covered the wetfall sampler. A precipitation sensor would be triggered with the first few raindrops at the beginning of a storm event. At this point, the movable "roof" would slide over and cover the dryfall collecting bucket, and thus expose the wetfall bucket. At the end of a rainfall event, the "roof" would slide back over the wetfall collecting bucket, thus enabling collection of dryfall samples once again. Both wetfall and pre-storm dryfall samples were collected after the completion of a storm event. In the case of an extended period of dry weather, the dryfall buckets were retrieved and replaced at 5 to 7 day intervals. Samples were analyzed using accepted chemical techniques which are summarized in Chapter 4 of the Final Report of OWML (1983). Wet and dryfall loading rates were computed by utilizing known relationships between the surface area of the bucket, the duration of the collection interval and the concentration (wetfall) or mass (dryfall) of the captured pollutants. Table 4.1 provides a complete list of the parameters which were sampled during the course of the study.

Table 4.1  
PARAMETERS ANALYZED IN ATMOSPHERIC SOURCE  
LOADING INVESTIGATIONS

| <u>PARAMETERS</u>         | <u>SAMPLING METHOD</u> |                |               |
|---------------------------|------------------------|----------------|---------------|
|                           | <u>WETFALL</u>         | <u>DRYFALL</u> | <u>HI-VOL</u> |
| <u>Plant Nutrients</u>    |                        |                |               |
| Total Nitrogen            | X                      | X              | X             |
| Nitrate + Nitrite         | X                      | X              | X             |
| Total Kjeldahl Nitrogen   | X                      | X              | X             |
| Soluble Kjeldahl Nitrogen | X                      | X              | X             |
| Ammonia                   | X                      | X              | X             |
| Total Phosphorus          | X                      | X              | X             |
| Total Soluble Phosphorus  | X                      | X              | X             |
| Ortho-phosphate           | X                      | X              | X             |
| Total Suspended Solids    | X                      | -              | -             |
| Total Solids              | -                      | X              | -             |
| Five Day BOD              | +                      | -              | -             |
| COD                       | X                      | X              | -             |
| Trace Metals              | -                      | -              | -             |
| Cadmium                   | X                      | 0              | 0             |
| Copper                    | X                      | 0              | 0             |
| Iron                      | X                      | 0              | 0             |
| Lead                      | X                      | 0              | 0             |
| Nickel                    | X                      | 0              | 0             |
| Zinc                      | X                      | 0              | 0             |
| pH                        | X                      | -              | 0             |
| Alkalinity                | X                      | -              | 0             |

---

Key X = regularly  
 + = occasional  
 0 = extractable only  
 - = not sampled

Both the instrumentation and field operation of the atmospheric deposition monitors represented a significant advance over methods used in earlier studies within the region. Previous 208 studies conducted in the Northern Virginia suburbs had utilized bulk precipitation monitoring devices which did not segregate wet and dryfall samples (NVPDC, 1979). As a result, prior dryfall collected in the sampling buckets tended to enrich the concentration of wetfall samples, particularly during smaller rainfall events. Preliminary calculations made during this study have suggested that the error introduced by not segregating wet and dryfall can lead to overestimation of atmospheric deposition rates by up to 25 to 50 percent.

Four wetfall/dryfall monitors were operated at three stations within the Washington area. A fourth wetfall/dryfall station was also operated within the region, as part of another study (OWML, 1982). Their locations can be found in Figure 4.2. As can be seen in the map, the four stations form a rough diamond within the Washington metropolitan area. A short description of each site is provided below:

Burke Village Shopping Center, located in Burke, Virginia, a growing suburb in southern Fairfax County, had two wetfall/dryfall monitors installed. One was situated at ground level, while the other was mounted on the rooftop, approximately 15 feet high. The purpose of this set-up was to separate the atmospheric loads delivered from those generated near the surface by traffic. It was thought that resuspension of fine materials by traffic might occur. Both monitors operated from February to December, 1981. Thirty wetfall samples and 30 dryfall samples were collected at ground level, while 39 wetfall and 49 dryfall samples were collected from the roof. In addition, a runoff monitoring station was located at the bottom of the parking lot.

Hains Point, is located in the District of Columbia, across from the National Park Service Headquarters in East Potomac Park. This station was designed to measure atmospheric loading rates which would be typical of a downtown CBD area. 39 wetfall and 52 dryfall samples were collected between December 1981 and January 1982.

Stedwick, located in a townhouse/garden apartment complex in Montgomery Village, in Montgomery County, Md., was used to characterize atmospheric loading rates typical of suburban areas (along with the other suburban site, Burke Village Shopping Center). 17 wetfall samples and 29 dryfall samples were collected between June and December, 1981. This site was also served by an urban runoff monitoring station.

Occoquan Chesapeake Bay Program Site, located adjacent to several farming operations in northern Prince William County, was operated between January 1980 and May 1981 as part of an earlier study (OWML, 1982). 52 wetfall and 54 dryfall samples were collected over the 17 month sampling interval. Located in a predominantly rural area, this station was assumed to represent the atmospheric load which might be expected to occur over rural areas in the Washington region. As such, it was used for comparative purposes.

#### TSP Monitoring

Total Suspended Particulate filter mats collected from high-volume air samples were obtained from local air quality monitoring agencies, and analyzed

Figure 4.2  
LOCATION OF WETFALL/DRYFALL MONITORS



Figure 4.3  
LOCATION OF HI-VOL TSP AIR QUALITY SAMPLERS





for nutrient, trace metal and particulate content (a complete list of analyzed parameters can be found in Table 4.1). TSP mats consisted of 20x25 cm glass fiber filters and were transmitted in sealed plastic bags along with the relevant air flow data. This allowed for determination of the 24 hour average air mass concentration in units of  $\mu\text{g}/\text{m}^3$ . TSP mats were analyzed on a monthly basis from eight high-volume stations within the region. The names and locations of the hi-vol samples can be found in Figure 4.3. Sampling was conducted over a period of 22 months (May 1980 to January 1982).

## RESULTS OF THE ATMOSPHERIC SOURCE MONITORING STUDY

### 1. Average Annual Deposition Rates

The wetfall and dryfall data collected during this study was initially used to estimate average annual atmospheric deposition rates for urban, suburban and rural locations in the Washington metropolitan area. Table 4.2 presents average annual atmospheric deposition rates for selected pollutants and land uses in the Washington metropolitan region. These rates were calculated in the following manner: first, all of the wetfall concentration data at each station was volume weighted and converted into units of  $\text{lbs}/\text{acre}/\text{year}$  assuming an average year of precipitation (42 inches). Second, mean dryfall loading rates were calculated from the entire data set at each station, and were subsequently converted to units of  $\text{lbs}/\text{acre}/\text{dryfall collection interval}$ . To arrive at an estimate of annual dryfall loads, the loading rate data was multiplied by a factor which related the duration of the dryfall collection interval to the number of dry days per year. Wetfall and dryfall loads were then summed at each station to obtain an annual deposition load. Annual rates were calculated for three general land use categories: rural, suburban and urban areas. As will be shown in Section 3, this was the most consistent pattern of variation observed in the entire data set.

As can be seen in Table 4.2, deposition of total solids ranged from 98.6  $\text{lbs}/\text{acre}/\text{yr}$  at the rural site to 243.3  $\text{lbs}/\text{acre}/\text{yr}$  at the urban site. These solids tended to be highly enriched with trace metals, organic carbon and nutrients. Total nitrogen was the nutrient with the greatest overall deposition rate, with between 12.8 and 19.9  $\text{lbs}/\text{acre}/\text{yr}$  deposited annually. The nitrogen was generally split in equivalent organic and inorganic fractions and exhibited little variation between sites. Phosphorus was typically deposited at a much lower rate. At all 4 sites, annual loadings never exceeded a pound per acre. Of all the trace metals studied, iron (Fe) had the greatest deposition rate (1.57 and 5.60  $\text{lbs}/\text{acre}/\text{yr}$  at the suburban and urban sites, respectively). Since the ratio of dryfall iron to dryfall solids at the suburban site was equivalent to the crustal abundance of iron, the origin of the iron probably can be attributed to soil sources. The fact that the dryfall iron to solids ratio was twice as great as the crustal abundance of iron at the urban site suggests that anthropogenic sources were a significant factor in the observed iron loading at that site.

Copper loading rates were also greater at the urban site than at the two suburban ones. A reverse pattern was noted with zinc. Nearly twice as much zinc was reported at the suburban station than at the urban monitoring site. This trend, however, may be a sampling anomaly. Both suburban stations were enclosed

Table 4.2  
AVERAGE ANNUAL ATMOSPHERIC POLLUTANT LOADINGS  
IN THE WASHINGTON AREA

| CONSTITUENT            | RURAL (b) | SUBURBAN (c)<br>lbs/acre/year | URBAN (d) |
|------------------------|-----------|-------------------------------|-----------|
| Total Solids           | 98.6      | 154.7                         | 243.3     |
| Chemical Oxygen Demand | 198.7     | 133.4                         | 209.8     |
| Total Nitrogen         | 19.9      | 12.8                          | 17.0      |
| Organic Nitrogen       | 10.57     | 7.2                           | 10.2      |
| Nitrate-N              | 9.36      | 5.6                           | 6.8       |
| Ammonia-N              | 5.51      | 1.05                          | 1.02      |
| Total Phosphorus       | 0.71      | 0.50                          | 0.84      |
| Ortho-Phosphorus       | 0.28      | 0.26                          | 0.35      |
| Copper (e)             | N.D       | 0.21                          | 0.61      |
| Cadmium (ef)           | N.D       | 0.09                          | 0.0025    |
| Chromium (ef)          | N.D       | 0.112                         | 0.008     |
| Iron (ef)              | N.D       | 1.573                         | 5.6       |
| Lead (e)               | 0.06      | 0.44                          | 0.53      |
| Manganese (ef)         | N.D       | .072                          | 0.299     |
| Nickel (ef)            | N.D       | 0.557                         | 0.076     |
| Zinc (e)               | 0.67      | 1.35                          | 0.65      |

(a) - Wetfall loads were computed using the formula:

$$Q = 5.39 \times C = \text{lbs/yr.}$$

where:

Q = 1.78 (the approximate volume of rainfall in inches which corresponds to the volume which falls during an average year of precipitation).

C = value weighted mean concentration (in mg/l) of the wetfall samples, (median values were substituted for those parameters exhibiting a log normal distribution).

Dryfall loads were computed by multiplying the mean mass deposition rate for all the dryfall samples by a factor which relates the average dryfall sample interval (6-7 days) to the number of dry days per year (assumed to be 340 or 95% of the time).

(b) - Values converted from data supplied in OWM (1982) Wetfall/Dryfall sampling conducted on a farm in the western portion of the Occoquan Watershed between Jan 1980 - May 1981.

(c) - Steadwick and Burke Ground NUTP atmospheric source stations: Steadwick located in suburban Montgomery County adjacent to a moderate density townhouse development. Burke located in shopping center parking lot in suburban Virginia (Apr. 1981 - January 1982).

(d) - Haines Point NUTP wetfall/dryfall collector data from Dec. 1980 to January 1982.

(e) - extractable metals

(f) - These estimates of loading rates should be considered provisional, as the small number of measurements (6 to 13) are probably not sufficient to adequately characterize rates. Also, in many cases, total deposition rates were very close to detection limits.

N.D - No data available.

by galvanized steel fences, which can emit zinc as they corrode. Chromium, cadmium and nickel loading rates were also higher at the suburban sites, particularly at the Burke Village Center site, than at the urban site. Since these three metals, like zinc, are to some degree related to automobile leakage and corrosion, perhaps this trend reflects the proximity of parking lots (some data to support this hypothesis is provided in Section 3). Lead loading rates exhibited a slight increase between urban and suburban sites. As the dominant source of lead loadings is motor vehicle exhaust, there appears to be a relatively small difference in the impact of motor vehicle emissions between suburban and urban areas.

## 2. Relative Importance of Wetfall and Dryfall Loads in the Washington Area

The wet and dryfall components of the overall atmospheric load are presented in graphical form in Figure 4.4. This discussion will emphasize trends in regional dryfall and wetfall patterns, and the relative importance of each depositional mechanism for selected pollutants.

### Patterns in Regional Dryfall Loadings

Several interesting trends emerge from the series of graphs depicted in Figure 4.4. Of particular note is the clear tendency for dryfall solids loadings to progressively increase from the rural to the urban sites. A similar trend was observed for total phosphorus, total nitrogen, and trace metal dryfall loading rates. Ortho-phosphorus, COD and organic nitrogen dryfall loading rates also increased between rural and urban sites, but were at their lowest at the suburban sites.

### Patterns in Regional Wetfall Loadings

As can be seen in Figure 4.4, wetfall loading rates exhibited few consistent regional patterns. Total solids, COD, ortho-phosphorus and lead wetfall loading rates remained relatively constant between the rural, suburban and urban sites, while wetfall loading rates for most forms of nitrogen were significantly higher at the rural sites, compared to either the urban or suburban sites. This latter trend was particularly evident for ammonia and organic nitrogen. A closer examination of the raw wetfall loading data revealed that the high nitrogen loadings observed at the rural site were deposited in a few precipitation events with extremely high concentrations of ammonia and organic nitrogen. These episodic pulses of nitrogen were in sharp contrast to the much lower wetfall loadings observed during most precipitation events (which were similar to those experienced at the urban and suburban sites). Given the close proximity of several crop and livestock operations which applied significant levels of liquid manure and nitrogenous fertilizers, and the relative synchronicity between the timing of these applications and the occurrence of ammonia wetfall pulses, it appears very likely that volatilization and decomposition processes occurring at these farms were a considerable localized source of volatile nitrogen wetfall deposition.

### Comparative Importance of Wetfall and Dryfall

The relative importance of wetfall and dryfall depositional mechanisms varied considerably with each pollutant and each site. Some pollutants were

Figure 4.4  
COMPARATIVE ATMOSPHERIC DEPOSITION RATES BETWEEN  
RURAL, SUBURBAN AND URBAN STATIONS

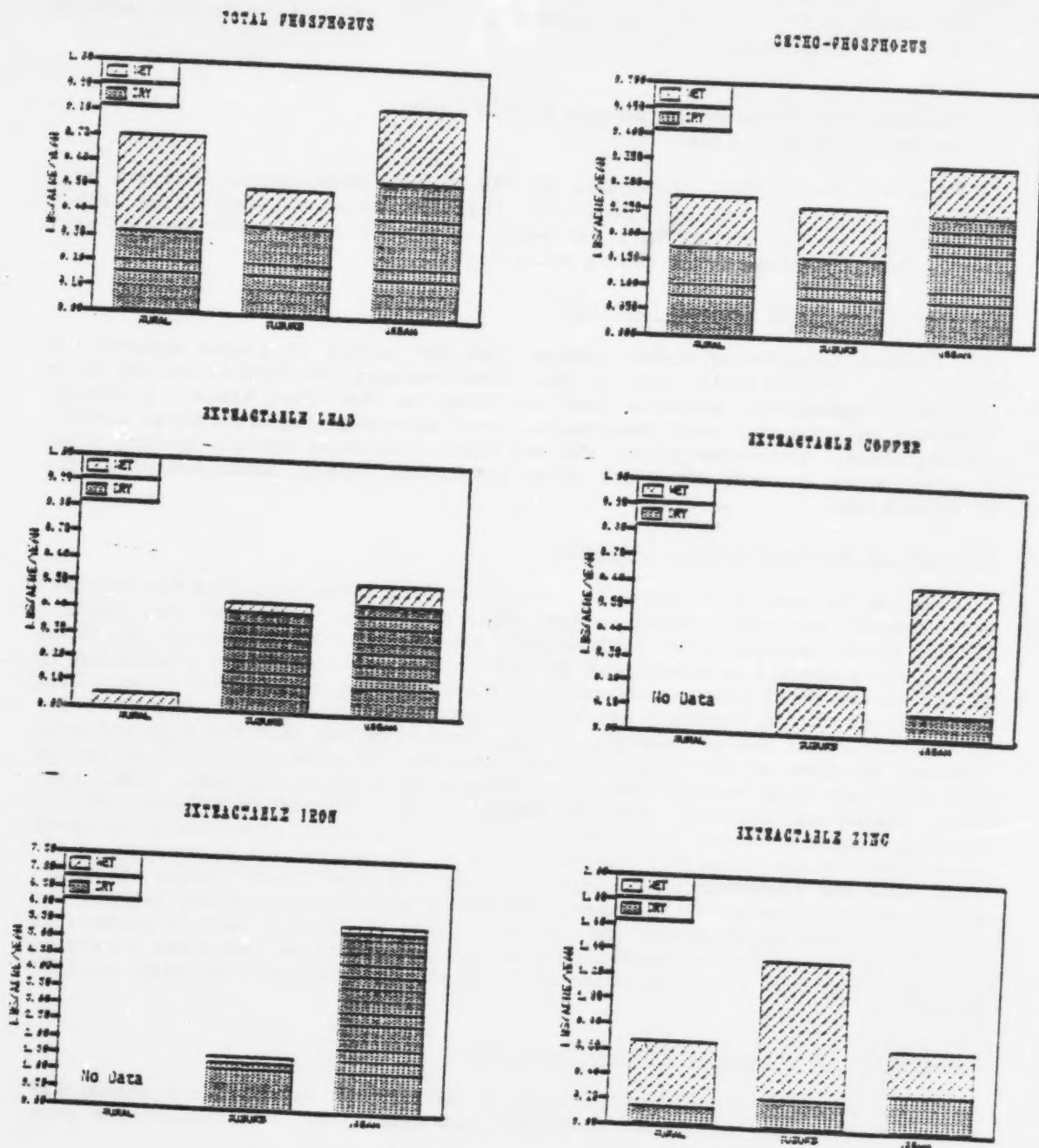
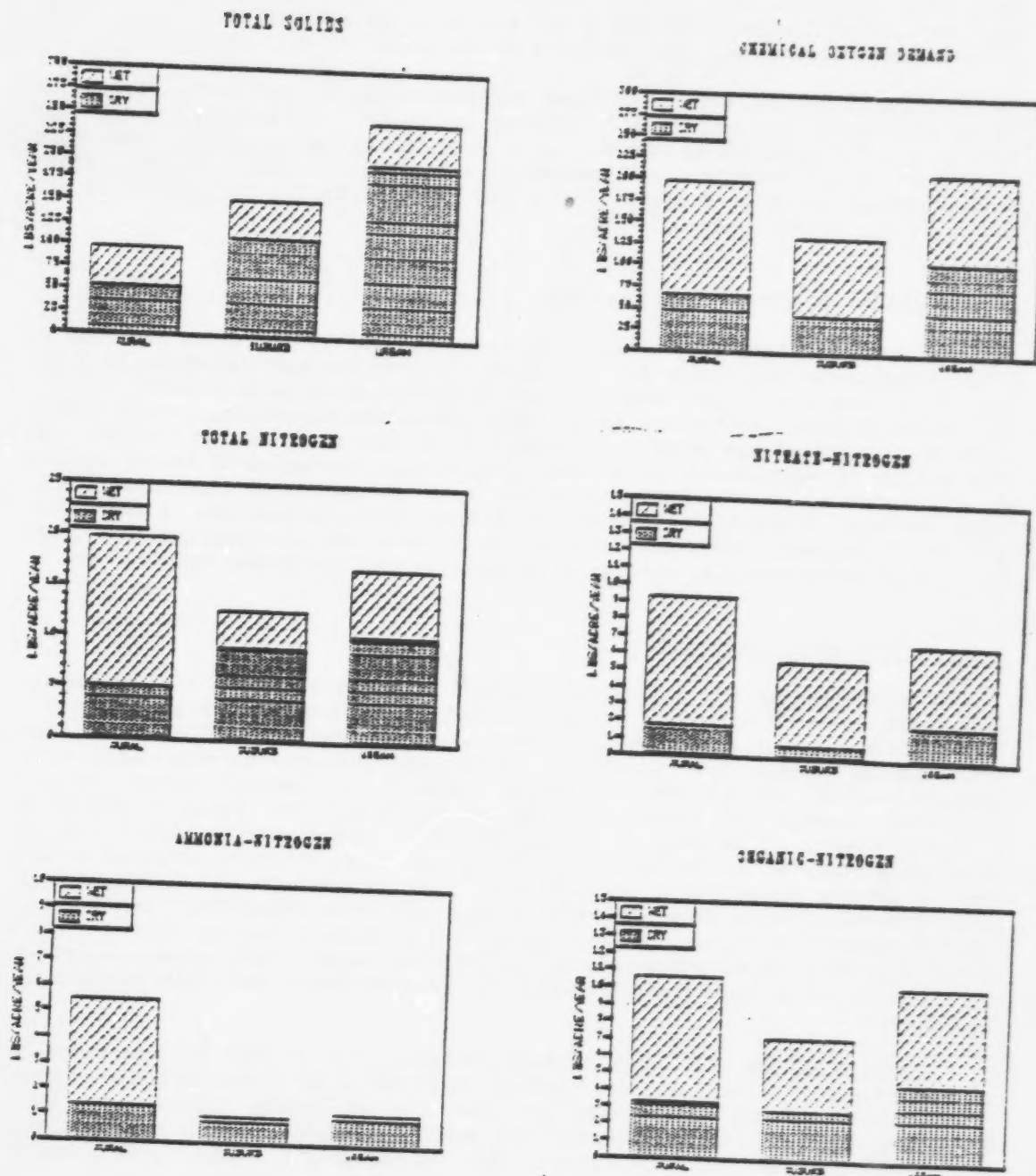




Figure 4.4  
COMPARATIVE ATMOSPHERIC DEPOSITION RATES BETWEEN  
RURAL, SUBURBAN AND URBAN STATIONS



chiefly deposited in dryfall, whereas other pollutants were primarily delivered in wetfall. For example, most of the nitrogen load was supplied by wetfall (Total Nitrogen, 62 to 74 percent; Nitrate 70-85 percent; Organic Nitrogen 56 to 69 percent) while most of the phosphorus load was delivered in dryfall (Total Phosphorus 46-65 percent; Ortho-phosphorus 62-72 percent). Similarly, 51-66 percent of the Chemical Oxygen Demand was measured in wetfall, in contrast to a range of 18 to 45 percent for total solids. Some metals, such as copper and zinc, were typically deposited in wetfall (>75 percent). Others metals which were more closely associated with total solids (iron and lead) were more likely to be deposited in dryfall, particularly at the urban and suburban sites.

The practical implication of these comparisons is related to the probability of delivery of wet and dryfall products in runoff. For example, if a pollutant is chiefly supplied by wetfall, it is more likely that a greater proportion of it will become immediately entrained in urban runoff. Also, wetfall pollutant loadings would be expected to be much more difficult to control at the source (i.e., street sweeping).

### 3. Variability In Atmospheric Loadings

As noted earlier, many dynamic factors collectively influence the rate at which atmospheric pollutants are deposited. Some of the most important of these factors include the nature, magnitude and proximity of emission sources, and local meteorological conditions (e.g., wind speed and direction, precipitation frequency). One of the principal objectives of this study was to document the variability in atmospheric deposition rates within the region to assess whether or not deposition and accumulation factors could be applied on a regional basis. Three measures of atmospheric deposition variability were examined in detail using the 95 percent confidence interval as a criterion of significance. These were: station-to-station, season-to-season, and roof-to-ground variability.

#### Station-to-Station Variability

Mean and median dry and wetfall loading rates from each of the NURP monitors were compared utilizing parametric and non-parametric statistical tests (the nature and application of these tests are described in the NVPDC Final Contract Report, 1983). The results indicated that there were no statistical differences at the 95 percent confidence interval in central values for all parameters (except COD) measured at the two suburban sites (Stedwick and Burke Village, Rooftop). As will be discussed later, significantly higher loading rates were observed at the Burke Village Ground level monitor, compared to the rooftop monitor installed at the same site. The greatest overall differences in dryfall loading rates were observed between the urban Hains Point monitor and the two suburban stations. Significantly higher dryfall loading rates were reported for Hains Point for nearly all parameters except lead, organic-nitrogen and ammonia, which displayed no statistically significant variation between any of the sites.

Analysis of the station to station variability of wetfall loading revealed no statistically significant differences in either mean or median loading rates between any of the four stations for the following pollutants: COD, ortho-phosphorus, nitrate, ammonia and total nitrogen. Significantly higher wetfall loadings of zinc were reported at both suburban stations, when compared

to the urban station. Conversely, wetfall total phosphorus loads were significantly greater at the Hains Point site, compared to the two suburban stations. Stedwick and Burke Village shopping center exhibited consistently similar wetfall loading rates for most parameters.

#### Season-to-Season Variability

Mean and median dryfall/wetfall loading data were statistically examined to identify seasonal variations in atmospheric deposition. This analysis suggested that dryfall loadings within the region followed a distinct and consistent seasonal pattern. The highest dryfall loadings occurred in the Spring, whereas the smallest dryfall loadings were experienced during the summer months. During the Fall and Winter, dryfall loading rates climbed gradually, eventually approaching levels observed during the Spring. This general pattern was observed for total solids, COD, total nitrogen, ammonia, organic nitrogen and zinc. Several parameters exhibited little or no seasonal variation in dryfall loadings. These included ortho-phosphate, copper and lead.

A similar, but less pronounced seasonal pattern could also be discerned in the wetfall loading data. As with the dryfall data, the wetfall loadings were greatest in the Spring, and smallest during the Summer months. However, wetfall loadings reached a second peak in the Fall, only to drop again in the Winter. This general seasonal pattern was noted for total phosphorus, total nitrogen, nitrate, ammonia, and organic nitrogen loadings. As with the dryfall data, several parameters exhibited little overall variation in seasonal loading rates. These parameters included ortho-phosphate, copper, zinc and COD.

Several factors could be cited to explain the general seasonal patterns in both the wetfall and dryfall loading data. For example, the high solids and nutrient loadings observed in the Spring could possibly be attributed to annual release of nutrient-rich pollen by flowering plants during this season. Another possible explanation for higher dryfall loading rates in the Spring and Winter could be due to local meteorological effects. As can be seen in the following table, average wind speeds were greatest in the Spring and Winter, and slightly lower in the Summer and Fall. Thus, there was probably a greater likelihood of wind erosion and resuspension during those months (particularly in the winter, when vegetative cover is not established). The fact that the prevailing wind direction changes seasonally also may have an influence on dryfall loadings. During the summer, the Washington area is dominated by tropical high pressure systems, and as a result, the prevailing wind direction is usually southerly. Arctic air masses largely control atmospheric circulation in the other months, and consequently, prevailing winds typically are recorded from the North and West during these seasons. This phenomena probably has important impacts on dryfall loadings, since southerly winds pass over the less industrialized south or even over the ocean, whereas the northwesterly winds may transport aerosols from the more heavily industrialized Ohio Valley area.



# METEOROLOGICAL CONDITIONS DURING THE ATMOSPHERIC STUDY NATIONAL AIRPORT, 1981

|        | Precipitation<br>(inches) | Prevailing<br>Wind(s) | Average Speed<br>(mph) |
|--------|---------------------------|-----------------------|------------------------|
| Winter | 6.0                       | W-SW                  | 11.1                   |
| Spring | 7.6                       | NW-NWW                | 11.5                   |
| Summer | 11.3                      | S-SW                  | 9.0                    |
| Fall   | 5.9                       | N-W                   | 10.2                   |

Source: NWS, 1982

Perhaps this factor can account for the lower atmospheric loadings observed during the summer. Another possible factor which may play a role in determining seasonal patterns could be precipitation frequency. The season which experienced the lowest wetfall loadings (Summer) was also associated with the month which had the greatest volume of precipitation. The other seasons, which were drier than normal, had significantly higher wetfall loadings. Therefore, it is possible that wetfall loading rates may decline in months of abundant moisture, since previous storms may wash-out pollutants which would have been available for subsequent storms.

## Roof-to-Ground Variability

The monitoring arrangement for the Burke Village Shopping Center station was designed to collect dryfall/wetfall samples at both rooftop and ground level locations, to determine if atmospheric loading rates vary significantly with height. As might be expected, there were no significant differences in wetfall loading rates between the rooftop and ground level monitors. Indeed, central values were usually identical between the two monitors. (One exception was Zinc, which exhibited higher overall wetfall loadings at the rooftop level. As noted earlier, this may be a sampling anomaly caused by corrosion of the galvanized fences enclosing the monitor.)

By way of contrast, sharp differences in dryfall deposition rates were noted in the data. The ground level monitor recorded significantly higher dryfall loadings for many pollutants, many of which were associated with particulates. These pollutants included total solids, total nitrogen, ortho-phosphorus, organic nitrogen, cadmium and zinc. In most cases the average difference between mean and median values between the roof and ground was on the order of 25 to 50 percent. Some pollutants remained more or less constant between the ground and the roof (manganese, lead, iron, COD, total phosphorus and ammonia), while only two showed higher concentrations at rooftop levels (Chromium and Nickel). In the case of the latter two metals, it is not clear whether the higher concentrations at the rooftop level were actually representative of normal conditions, since only a relatively small number of samples analyzed.

Given the clear tendency towards higher dryfall loading rates at ground level, it appears fairly certain that dryfall rates at Burke Village Center were being positively influenced by vehicular traffic. The exact mechanism responsible for this influence, however, is difficult to identify. For example, the



higher loadings could possibly be attributed to ground level emissions from motor vehicles, or may merely represent the resuspension of fine dust caused by the passage of traffic. In any event, the observed variation in dryfall loading rates at the Burke Village Shopping Center station, has little overall effect on the total load of pollutants deposited. This is mainly due to the fact dryfall was the least important depositional mechanism for the pollutants which exhibited the greatest roof-to-ground variability.

#### 4. Composition of the Washington Metropolitan Airshed

##### Regional Variability

Table 4.3 details the results of the chemical analysis of the total suspended particulate filter mats collected at eight high volume air quality samplers. The stations can be divided into two groups, on the basis of their distance from the urban core. The first group is composed of three urban stations: Aurora, Catholic University, and Hadley Hospital, all of which are located in the D.C. area. The second group is composed of five stations, two of which are located in suburban Rockville and Fairfax City (Massey), and three which are situated on the outer fringe of the Washington metropolitan area, (Hall, Laurel, and Ft. Belvoir).

One of the interesting aspects of the hi-vol data is the striking uniformity in the concentration of total suspended particulates (TSP) throughout the region. The maximum range in TSP levels between any two stations is only 20 percent. Similar regional uniformity is also noted in total phosphorus, ortho-phosphorus, lead, zinc, manganese and cadmium levels. Chromium and organic nitrogen levels appear to be greater at the urban stations than the outer stations. No distinct pattern could be discerned for organic nitrogen, copper or iron, as concentrations varied substantially among all stations. A very anomalous pattern is evident for nitrate; levels recorded at the three Maryland air quality stations were from 2 to 5 times higher than those observed at Virginia and D.C. stations. No immediate explanation for this phenomena is suggested.

Further definition of regional patterns in TSP levels and composition is provided in Table 4.4, which compares pollutant levels during six days in which synoptic samples were collected at all eight stations. In general, this data follows the same patterns of variability exhibited by the entire dataset, although somewhat greater variability is observed.

##### Historical Variability

Table 4.5 compares summer TSP enrichment levels observed in this study with those reported by Kowalzyk (1982) for the summer of 1976. As there are inherent problems with comparing data derived from different sampling networks which operate over a different sampling interval, this comparison is made for illustrative purposes only. Both studies reported very similar TSP, nitrate, zinc and copper concentrations throughout the region, suggesting that no major changes in the ambient quality of the air mass. What is very striking is the nearly 60 percent drop in ambient air lead levels. This decrease in atmospheric lead levels corresponds to a similar decrease noted in lead loadings in urban runoff between 1976 and 1980 (NVPDC, 1983), and can probably be attributed to gradual decrease

Table 4.3  
MEAN CONCENTRATION OF POLLUTANTS IN HI-VOL TSP  
FILTERS: LUMPED DATA (ug/m3)

| STATION      | TSP   | TKN  | TP   | NO2,3 | OP   | ECU  | EPB  | EZN  | EMN  | EFE  | ECR  | ECD  |
|--------------|-------|------|------|-------|------|------|------|------|------|------|------|------|
| Pooled       | 57.32 | 0.62 | 0.04 | 2.29  | 0.04 | 0.10 | 0.21 | 0.08 | 0.02 | 0.22 | 0.03 | 0.00 |
| Catholic U.  | 61.91 | 0.83 | 0.04 | 0.93  | 0.03 | 0.09 | 0.22 | 0.05 | 0.02 | 0.41 | 0.12 | 0.00 |
| Hadley Hosp. | 61.76 | 0.81 | 0.05 | 1.08  | 0.03 | 0.28 | 0.24 | 0.07 | 0.01 | 0.20 | 0.11 | 0.00 |
| Hall         | 51.02 | 0.44 | 0.03 | 4.05  | -    | 0.07 | 0.20 | 0.08 | 0.01 | 0.11 | 0.00 | 0.00 |
| Rockville    | 52.66 | 0.26 | 0.03 | 4.35  | -    | 0.02 | 0.25 | 0.11 | -    | -    | -    | -    |
| Laurel       | 61.46 | 0.50 | 0.04 | 4.55  | -    | 0.03 | 0.23 | 0.09 | 0.05 | 0.24 | 0.05 | 0.00 |
| Aurora       | 59.71 | 0.72 | 0.05 | 1.19  | 0.05 | 0.09 | 0.29 | 0.09 | 0.02 | 0.20 | 0.00 | 0.00 |
| Ft. Belvoir  | 53.01 | 0.65 | 0.04 | 1.15  | 0.04 | 0.11 | 0.12 | 0.08 | 0.01 | 0.10 | 0.00 | 0.00 |
| Massey Bldg. | 54.41 | 0.55 | 0.03 | 0.75  | 0.04 | 0.06 | 0.18 | 0.07 | 0.02 | 0.31 | 0.00 | 0.00 |

Table 4.4  
MEAN CONCENTRATION OF POLLUTANTS IN HI-VOL TSP  
FILTERS: SYNOPTIC EVENTS (ug/m3)

| STATION      | TSP   | TKN  | TP   | NO2,3 | OP   | ECU  | EPB  | EZN  | EMN | EFE | ECR | ECD |
|--------------|-------|------|------|-------|------|------|------|------|-----|-----|-----|-----|
| Pooled       | 53.86 | 0.49 | 0.05 | 2.49  | 0.01 | 0.08 | 0.21 | 0.05 | -   | -   | -   | -   |
| Catholic U.  | 59.13 | 0.47 | 0.03 | 0.82  | 0.01 | 0.12 | 0.19 | 0.04 | -   | -   | -   | -   |
| Hadley Hosp. | 59.85 | 0.57 | 0.07 | 0.98  | 0.02 | 0.13 | 0.29 | 0.09 | -   | -   | -   | -   |
| Hall         | 48.50 | 0.41 | 0.04 | 4.07  | -    | 0.07 | 0.15 | 0.04 | -   | -   | -   | -   |
| Rockville    | 53.15 | 0.31 | 0.04 | 4.65  | -    | 0.02 | 0.23 | 0.17 | -   | -   | -   | -   |
| Laurel       | 49.73 | 0.29 | 0.04 | 4.17  | -    | 0.02 | 0.15 | 0.05 | -   | -   | -   | -   |
| Aurora       | 62.33 | 0.85 | 0.06 | 0.25  | 0.00 | 0.09 | 0.44 | 0.00 | -   | -   | -   | -   |
| Ft. Belvoir  | 53.58 | 0.74 | 0.06 | 0.80  | 0.01 | 0.07 | 0.13 | 0.01 | -   | -   | -   | -   |
| Massey Bldg. | 44.58 | 0.43 | 0.03 | 0.53  | 0.01 | 0.11 | 0.09 | 0.00 | -   | -   | -   | -   |

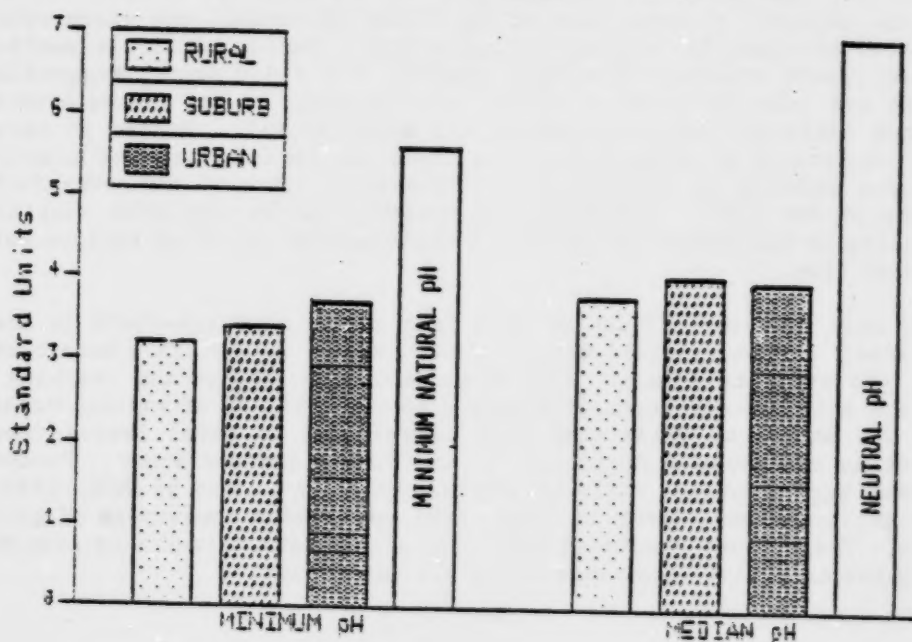
\*samples collected 4/15/80, 5/15/80, 7/14/80, 2/15/81, 4/16/81, 5/16/81

Table 4.5  
COMPARISON OF MEAN REGIONAL TSP ENRICHMENT LEVELS  
BETWEEN THE SUMMER OF 1976 AND 1980

|                        | 1976 <sup>(a)</sup> | ug/m <sup>3</sup> | 1980 <sup>(b)</sup> |
|------------------------|---------------------|-------------------|---------------------|
| TSP                    | 65                  |                   | 68                  |
| Cadmium                | 0.002               |                   | 0.009               |
| Copper                 | 0.020               |                   | 0.013               |
| Lead                   | 0.440               |                   | 0.189               |
| Manganese              | 0.017               |                   | 0.020               |
| Zinc                   | 0.09                |                   | 0.12                |
| Nitrate <sup>(e)</sup> | 2.16                |                   | 2.25                |

- (a) Data from Kowalczyk *et al* (1982). 10 TSP sampling stations located throughout the Washington metropolitan area, which monitored 18 daily events between August 10 to September 13, 1976.
- (b) NURP Hi-vol data, from 8 air quality stations situated throughout the Washington metropolitan area. Monthly measurements June-September 1980.
- (e) Nitrate is usually found in the atmosphere as an aerosol, and is not closely associated with TSP.

Figure 4.5  
MINIMUM AND MEDIAN PRECIPITATION pH MEASUREMENTS:  
RURAL, SUBURBAN AND URBAN STATIONS



in the lead content in gasoline which occurred over this period. (Motor vehicle exhaust has been cited as the dominant source of atmospheric load.)

## 5. Acid Precipitation in the Washington Region

The acidity of precipitation is measured in terms of "pH" or potential hydrogen. Defined as the negative logarithm of hydrogen ion concentration in solution, the pH scale ranges from 0 to 14. A value of 7 indicates a neutral solution (i.e., neither acid or alkaline). Values above 7 are representative of alkaline conditions, whereas values below 7 indicate the presence of acid solutions. Since pH is measured on a logarithmic scale, a change of one pH unit is in reality a tenfold change in acidity. Thus, a pH of 5 is 100 times more acidic than a pH of 7.

Laboratory pH measurements were performed on each of the wetfall samples collected during the course of the atmospheric monitoring study, and this data is displayed in Figure 4.5. Mean and median pH values consistently range between 3.9 and 4.2 units. Minimum and Maximum pH values were 3.2 and 5.5 units, respectively. As can be seen in the figure, little variation was observed in median pH values between the four monitors within the region. Similarly, the pH of rainfall remained remarkably consistent from season to season, and from ground to roof. Natural atmospheric processes, such as the absorption of carbon dioxide to form weak carbonic acids, cannot account for pH values below 5.0 to 5.6 units. (EPA, 1983). Therefore, the acidity of rainfall observed in the Washington region can probably be attributed to anthropogenic sources, such as sulfate or nitrogen emissions. Earlier studies by Kowalzyk et al (1982) suggested that sulfates account for the bulk of the acidity below 5.6 units in the region. Kowalzyk et al also found high correlations between atmospheric sulfates and selenium concentrations, a common marker element of coal-fired power plants, which suggests some association between acid rain and coal-fired power generation.

What are the practical implications of the observed acidity of rainfall within the region? A comparison of pH values in wetfall and storm runoff was made at two stations for synoptic storm events. Median pH levels monitored at the urban runoff stations were approximately 6.8 - 7.0 units, suggesting that the soils and rocks of pervious areas, and the concrete and paving materials of impervious surfaces, served to buffer the acid rainfall. Runoff pH levels did exhibit considerable variability. As much as three orders of magnitude of change were reported at some stations. However, minimum values never fell below 5.0 units at any time. Therefore, it probably can be concluded that the acid rain falling in the region has no direct influence on the pH of surface waters at the present time.

The more indirect effects of acid rain may be more important in the Washington area. Acidic rainfall tends to pull out or desorb trace metals attached to soil and other materials. This phenomenon can involve the leaching of cations from soils or corrosion of metals from the surfaces of various urban materials. The extent to which acid rain contributes to metal losses from these processes is not known with precision, and awaits further study. Recent trace metal sampling of surface soils in grassed swales conducted by OWML (1983) indicated significant enrichment of zinc, lead and cadmium downstream of galvanized culverts. The authors concluded that corrosion of the culverts by acid rain was probably the causative agent underlying the enrichment.



Other possible impacts which acid rain may have on the region are the inhibition of plant growth and accelerated erosion/corrosion of the masonry, monuments, paint and metals which comprise the urban landscape. The precise nature and extent of both effects, however, are not well understood at the present time (EPA, 1983) since it is extremely difficult to isolate the damage caused by acid rain, from the damage caused by other urban factors (micrometeorologic conditions, other air pollutants, etc.). At any rate, conclusions as to the impact of the acid rain within the region cannot be drawn until further research is completed.

#### 6. Relationship of Atmospheric Deposition to Urban Runoff Quality

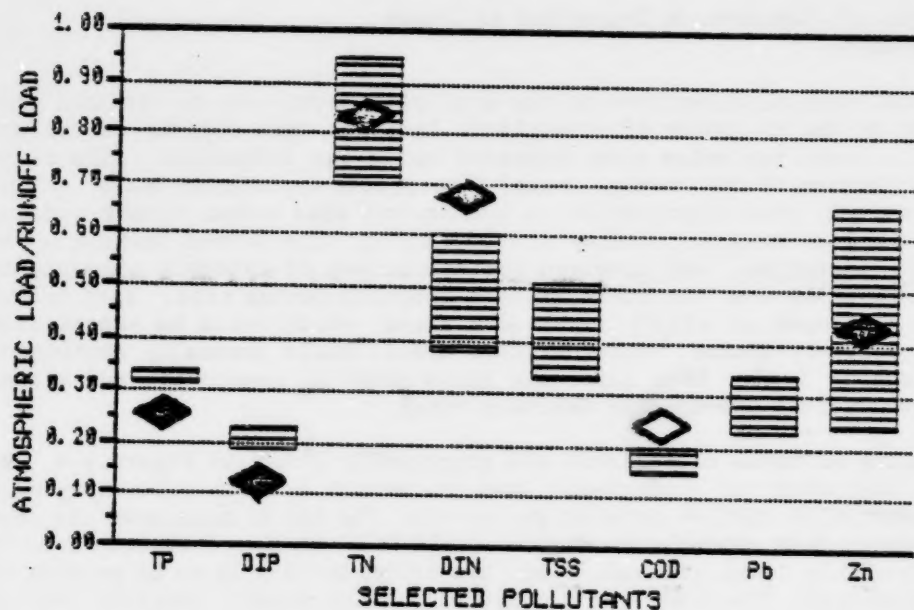
One of the central objectives of the monitoring study was to obtain a general estimate of the delivery of atmospheric loadings into surface waters via urban runoff. These estimates were prepared using two techniques. The first involved a comparison of the average annual atmospheric deposition loads (calculated in Section 1) with representative Washington area urban runoff loading rates, determined in earlier studies (NVPDC, 1979). The second technique was more empirical in nature, and involved the comparison of synoptic atmospheric and runoff loading data at the Burke Village Shopping Center site. Both calculations were developed in highly impervious areas, which would be expected to have greater delivery ratios. More pervious areas, while generally exhibiting lower urban runoff loads, have important sinks such as vegetation and soils, which can lower overall atmospheric delivery rates.

The results of these comparisons are graphically shown in Figure 4.6. As can be seen, the ratio of atmospheric load to runoff load calculated by each method is essentially similar for most parameters. As far as nutrients are concerned, it appears that atmospheric sources could conceivably contribute from 70 to 95 percent of the total nitrogen load, and approximately 20 to 35 percent of the total phosphorus. The atmospheric component of the overall nutrient load is somewhat smaller for the inorganic and more biologically available forms of each nutrient. Only between 40 and 70 percent of the inorganic nitrogen runoff load and only 10 to 25 percent of the inorganic phosphorus runoff load could be supplied by atmospheric sources.

Deposition of total solids from the atmosphere can account for between 35 percent to 50 percent of the average annual urban runoff load (i.e., highly impervious areas such as shopping centers and central business districts). In all likelihood, the importance of atmospheric deposition of solids in less impervious residential areas is inconsequential, (as other sources of sediment predominate). Similarly, the importance of atmospheric BOD loadings appears not to be great. Atmospheric deposition of lead (25 - 35 percent), and zinc (25 to 65 percent) could be of local importance. (The proportion could be greater if the contribution of leached or corroded metals from acid rain is also included.)

In summary, atmospheric deposition appears to be a moderate source of pollutants in urban runoff. However, with the exception of nitrogen, atmospheric deposition is not the major source.

Figure 4.6  
COMPARISON OF ATMOSPHERIC AND RUNOFF NONPOINT LOADS  
IN HIGHLY IMPERVIOUS AREAS



Notes:

- (1) STRIPED BOXES indicate the range in the ratio of the average annual atmospheric load (Table 2) and the average annual runoff load (NVPOC, 1979) in the Washington area for suburban shopping centers and downtown central business districts. The use of 1979 Guidebook loading rates is warranted because preliminary statistical analysis has confirmed that there were no significant difference between 1980-1981 NURP loading rate datasets and the 1976-1977 208 loading rate dataset, for most parameters (i.e., the 208 dataset served as the basis for the Guidebook values). One exception, however, was lead, which was approximately 50 percent lower in the more recent and extensive NURP study. Therefore, the average annual runoff loading rate was reduced correspondingly for this parameter.
- (2) SOLID BLACK DIAMONDS represent atmospheric/runoff load ratios computed from NURP. Field data for Burke Shopping Center, which had both a wetfall/dryfall collector and a runoff monitoring station. Ratios were developed with specific precipitation data. Additional modifications were made to account for the dryfall component of the total atmospheric load.
- (3) WHITE DIAMOND involves a similar comparison (to 21) but involves the Burke Shopping Center wetfall/dryfall collector, and the Fair Oaks Shopping Center runoff station.

## 7. Major Sources of Regional Atmospheric Pollutants

Table 4.6 provides a general indication of the dominant regional emission sources which produce the atmospheric pollutant loads of concern. (It should be noted that the long range sources of atmospheric pollutants are not shown.) The major emission sources can be conveniently divided into three categories: 1) oil, coal and natural gas combustion products; 2) motor vehicle emissions; and, 3) fugitive emissions (i.e., the "nonpoint" sources of air pollutants such as roadway dust, wind erosion, refuse piles, etc.).

The best regional estimates available suggest that combustion products are not the major source of most air pollutants, and that either motor vehicles or fugitive emissions usually predominate. In the case of most of the nutrient forms, much of the atmospheric load is derived from fugitive or natural sources, over which little direct control can be exerted. One important exception is nitrate, which is primarily produced by both motor vehicles and combustion processes. The TSP load appears to be a result of all three emission categories. Some trace metals, such as copper, cadmium and lead are principally supplied by motor vehicles, while others (iron, chromium and manganese) are closely associated with the soil, and still others are principally combustion products (nickel).

## 8. Multiple Air and Water Quality Benefits of Source Controls

The previous section provided general indications regarding the relative importance of regional sources of air pollutants. The logical next step is to make some inference as to the potential effect that emission control strategies would have on reducing atmospheric deposition rates, and consequently, reducing the quantity of pollutants available for transport in urban runoff. The objective question being, of course, what spinoff effects might air quality control have on regional water quality? An answer to such a question involves analysis of three points.

1. Can the dominant regional sources of a given pollutant be effectively controlled (for example, is X emitted by the more controllable point or mobile sources, or is it emitted by less controllable sources such as natural background, fugitive or long range emissions)?
2. Assuming that X can be controlled effectively, is the deposition of X a major source of the load observed in runoff? (For example, atmospheric deposition supplies only 20 to 35 percent of the runoff P, but does supply between 70 and 95 percent of runoff N).
3. Again assuming that X is controllable, and is a major source of the runoff load of X, does X have any important influence on downstream water quality? (As an example, COD may not have the marked effect on the quality of urban streams that nutrients might exert).

A definitive answer to each of these questions for each pollutant is outside of the general scope of this report. A provisional evaluation of the possibility of multiple air and water quality benefits, however, is provided in the Table 4.7.

As mentioned previously, lead is a very good example of a positive spin-off effect of emission control on the quality of urban runoff. Since lead is prima-

Table 4.6  
DOMINANT SOURCES OF ATMOSPHERIC POLLUTANTS IN THE  
WASHINGTON METROPOLITAN AIRSHED

Total Suspended Particulates - soil, motor vehicles, oil/coal combustion  
Nitrate - motor vehicles, oil/coal combustion  
Organic Nitrogen - natural background/biological processes  
Ammonia - volatilization and decomposition of organic matter  
Total Phosphorus - soil ?  
Ortho-Phosphorus - soil ?  
Copper - motor vehicles, oil/coal combustion  
Cadmium - motor vehicles, fugitive emissions  
Chromium - soil, coal combustion  
Iron - soil, coal combustion  
Lead - motor vehicles, street dust  
Manganese - soil  
Nickel - oil and coal combustion  
Zinc - fugitive emissions, motor vehicles

---

Source: Kowalyczk et al, 1982 and EPA, 1983



rily emitted from motor vehicles, and the lead content of gasoline could be controlled, reductions in ambient atmospheric lead concentrations have been achieved. This, in turn, has led to a reduced rate of atmospheric deposition of lead, and has also reduced the supply available for subsequent delivery in urban runoff. This fact is especially noteworthy, since high levels of lead have very lethal effects on aquatic life and human health. As a result, the net result of the atmospheric lead emissions control program has been almost a proportional reduction of ambient atmospheric concentrations, deposition rates and runoff concentrations. Thus, given appropriate control effort, it would appear that control of other pollutants such as nitrate and cadmium could exhibit positive spin-off effects.

Other pollutants appear to have much less potential for positive spin-off effects. These include, phosphorus, oxygen-demanding materials, organic nitrogen and some trace metals. Most of these pollutants are contributed from natural or fugitive emission sources, which are not amenable to extensive control efforts. Additionally, atmospheric deposition of these pollutants is not a dominant source of observed urban runoff loads. As such, efforts to control these pollutants at their emission source would probably have no appreciable effect on urban runoff concentration.

Table 4.7  
EVALUATION FRAMEWORK FOR IDENTIFYING POSSIBLE POSITIVE  
WATER QUALITY SPINOFF BENEFITS FROM AIR QUALITY  
EMISSION CONTROLS

| Parameter        | (3)<br>Relative Importance<br>to Downstream<br>Water Quality | (2)<br>Importance of<br>Deposition as a<br>Runoff Source | (1)<br>Relative<br>Controllability |
|------------------|--------------------------------------------------------------|----------------------------------------------------------|------------------------------------|
| Nitrate-N        | High                                                         | High                                                     | High                               |
| Lead             | High                                                         | High                                                     | High                               |
| Cadmium          | ?                                                            | High?                                                    | High                               |
| Total Nitrogen   | High                                                         | High                                                     | Moderate                           |
| Total Solids     | Moderate                                                     | Moderate                                                 | Moderate                           |
| Zinc             | Moderate                                                     | Moderate                                                 | Moderate                           |
| Organic Nitrogen | Moderate                                                     | High                                                     | Low                                |
| Total-P          | High                                                         | Low                                                      | Low                                |
| Ortho-P          | High                                                         | Low                                                      | Low                                |
| Iron             | Low                                                          | ?                                                        | Low                                |
| Ammonia-N        | Low                                                          | Moderate                                                 | Low                                |
| COD              | Low                                                          | Low                                                      | Moderate                           |
| Nickel           | ?                                                            | ?                                                        | High                               |
| Copper           | ?                                                            | ?                                                        | ?                                  |

## CONCLUSIONS

Atmospheric monitoring effects in the Washington area NURP project included operation of four wetfall/dryfall monitors and chemical analysis of TSP filter mats from eight regional high volume air samplers, and comparisons with observed pollutant loadings in urban runoff. The major conclusions of this field study are as follows:

- Average annual atmospheric deposition rates calculated at urban, suburban and rural areas suggested a general trend toward greater deposition rates from rural to suburban to urban sites for most parameters. This pattern was most pronounced for dryfall, but was also evident for wetfall deposition rates for some parameters.
- Wetfall was the most important deposition mechanism for Total Nitrogen, Nitrate, Organic Nitrogen, COD, Copper and Zinc. By way of contrast, dryfall was relatively more important as a depositional mechanism for most soil related constituents, such as Total Solids, Iron, Lead, Total Phosphorus, and Ortho-phosphorus.
- Atmospheric deposition rates did not vary significantly between the two suburban stations monitored, but were somewhat greater at the urban site.
- In general, wetfall and dryfall rates were greatest in the spring, lowest in the summer, and intermediate in the fall and winter. Several factors were identified which might produce this seasonal pattern. They included: pollen release, precipitation frequency, wind speed and direction.
- Significant differences in dryfall rates (but not wetfall) were noted at ground and roof top monitors at the Burke Village monitor for some parameters. Ground level dryfall rates were approximately 25 to 40 percent higher for most parameters at ground level. Due to the proximity of motor vehicle traffic to the monitor, it is believed that either ground level emissions or re-entrainment of street dust were responsible for producing the higher ground level dryfall rates.
- Chemical analysis of TSP filters collected at eight regional high-volume air quality samplers revealed a striking uniformity in air mass concentration for total solids, phosphorus, lead, zinc, cadmium and manganese levels. No distinct regional patterns could be determined for nitrate, organic nitrogen, copper or iron, as air mass concentrations varied considerably among stations.
- Comparisons of atmospheric concentrations of pollutants between this study and a similar 1976 study suggested that while air mass concentrations of most pollutants had remained nearly constant between the summers of 1976 and 1980, the ambient air concentrations of lead had dropped by nearly 60 percent. The institution of controls on leaded gasoline is believed to be mostly responsible for this decline. Almost proportional reductions in the lead loadings in urban runoff were noted over the same period.

- pH measurements of rainfall in the Washington region showed a consistent pattern of acidity. Median pH values typically ranged between 4.0 and 4.1 units at all stations and during all seasons. The "acid rain" which occurs apparently does not influence the pH of surface waters, which is not surprising considering the well-buffered nature of local soils and rocks. Increased mobilization of trace metals from some urban surfaces caused by acid rain were noted at several monitoring sites. The regional impacts of acid rain on plants, soils, and materials is not known at present, and represents a crucial avenue of future research.
- Atmospheric loading represents a major source of the urban runoff load for several pollutants in highly urban areas. These include nitrogen, solids, zinc and lead. In the case of phosphorus and oxygen-demanding materials, other non-atmospheric sources appear to be more important in producing observed loads in urban runoff.
- The possibility of obtaining additional water quality benefits from the implementation of air emission control strategies is briefly discussed. One prominent example of such benefits includes the effective implementation of controls on lead emissions in recent years. This has been translated into nearly a proportional decrease in lead loadings in urban runoff.
- Ten major water quality parameters were evaluated through a three-stage process. This analysis suggested a reasonable potential for achieving positive water quality spin-off benefits through emission control for nitrate, cadmium and lead. Few spin-off benefits were likely to be achieved for the other parameters through emission controls.

## REFERENCES

- Environmental Protection Agency, 1983. The Acidic Deposition Phenomenon and its Effects: Critical Assessment Review Papers. Volume I and II. Office of Research and Development, Washington, D.C. EPA-600/8-83-016AB.
- Kowalyzk, G.S., G.E. Gordon and S.W. Rheingrover, 1982. Identification of Atmospheric Particulate Sources in Washington, D.C. Using Chemical Element Balances, Environmental Science and Technology, Vol. 16 p.79-90.
- National Weather Service, 1982. Monthly Climatological Summaries - National Capital Area. NOAA, NWS, Silver Spring, Maryland.
- Occoquan Watershed Monitoring Laboratory (OWML), 1982. Evaluation of Management Tools in the Occoquan Watershed: Final Contract Report #R806310010, prepared for the Virginia State Water Control Board.
- 
- \_\_\_\_\_, 1983. Final Contract Report on Washington Nationwide Urban Runoff Projects, prepared for the Metropolitan Washington Council of Governments, Water Resources Planning Board.
- Northern Virginia Planning District Commission (NVPDC), 1979. Guidebook for Screening Urban Nonpoint Pollution Management Strategies, prepared for Metropolitan Washington Council of Governments, Water Resources Planning Board.
- Northern Virginia Planning District Commission and Occoquan Watershed Monitoring Laboratory, 1978. Occoquan/Four Mile Run Nonpoint Source Correlation Study, prepared for Metropolitan Washington Council of Governments, Water Resources Planning Board.
- Northern Virginia Planning District Commission, 1983. Final Contract Report: Metropolitan Washington Nationwide Urban Runoff Project. Report prepared for Metropolitan Washington Council of Governments, Water Resources Planning Board.



**CHAPTER FIVE**  
**SPECIAL URBAN RUNOFF STUDIES**

## CHAPTER V

### SPECIAL URBAN RUNOFF STUDIES

This chapter briefly describes the principal findings of a series of special research studies undertaken to provide a more complete understanding of the nature and dynamics of urban runoff in the Washington region. These special studies included the:

- **Monitoring for Toxic Chemical Levels in Urban Runoff.** As part of the overall monitoring activities for each NURP project, EPA required that a limited monitoring effort be conducted to investigate the possible presence of any toxicants, such as organic pollutants, pesticides and trace metals, in urban stormwaters. One storm sample was collected at each of 15 different locations throughout the region and analyzed to determine the presence of over 125 toxic substances specified in EPA's Priority Pollutant List.
- **Comparison of Nonpoint Loading at Downtown and Suburban Central Business Districts (CBDs).** Pollutant concentrations in urban runoff from two highly impervious downtown catchments in Washington, D.C. were monitored and were subsequently compared to established suburban CBD loading rates.
- **Accumulation and Movement of Trace Metal within Urban BMPs.** - Six urban runoff monitoring stations which were serviced by grassed roadside swales or conventional detention basins were sampled for soil trace metal levels. Emphasis was placed on determining the movement of metals through the BMP and underlying soils.
- **Relative Bioavailability of Nutrients in Urban Runoff Study.** - Consisted of algal assay experiments to determine what effect, if any, that BMP's may have on inhibiting algal growth potential by way of nutrient limitation.
- **Settling Behavior of Pollutants in Urban Runoff.** - Consisted of laboratory settling column experiments to ascertain the degree of pollutant removal which could be achieved by physical settling alone.

The remainder of this chapter provides a brief synopsis of each special study. For the sake of brevity, only the major results and implications of each study are highlighted. (Reference is made to the appropriate technical documentation report at the end of each section if the reader desires a more complete description of the design, methodology, and results of each study). The chapter concludes with a summary of those specific findings obtained in the special studies which may have implications of particular interest for establishing future directions in urban runoff management.

Table 5.1  
U.S. EPA PRIORITY POLLUTANT LIST

|                                                                 |                                                  |                                     |
|-----------------------------------------------------------------|--------------------------------------------------|-------------------------------------|
| 1. Aldrin                                                       | 27. HALOGENATED ALIPHATICS                       | VII. PHENOLS AND CRESOLS            |
| 2. Aldrin                                                       | 28. Methane, bromo- (methyl bromide)             | 90. Phenol                          |
| 3. $\alpha$ -Hexachlorocyclopentadiene (a-HCH) (Algalin)        | 29. Methane, chloro- (methyl chloride)           | 91. Phenol, 2-chloro-               |
| 4. $\beta$ -Hexachlorocyclopentadiene ( $\beta$ -HCH) (Beta)    | 30. Methane, dichloro- (methylene chloride)      | 92. Phenol, 2,4-dichloro-           |
| 5. $\gamma$ -Hexachlorocyclopentadiene ( $\gamma$ -HCH) (Gamma) | 31. Methane, chlorodibromo-                      | 93. Phenol, 2,4,6-trichloro-        |
| 6. $\delta$ -Hexachlorocyclopentadiene ( $\delta$ -HCH) (Delta) | 32. Methane, dichlorodibromo-                    | 94. Phenol, pentachloro-            |
| 7. Chlordane                                                    | 33. Methane, tribromo- (bromoforn)               | 95. Phenol, 2-nitro-                |
| 8. DDT                                                          | 34. Methane, trichloro- (chloroforn)             | 96. Phenol, 4-nitro-                |
| 9. DDT                                                          | 35. Methane, tetrachloro- (carbon tetrachloride) | 97. Phenol, 2,4-dinitro-            |
| 10. DDT                                                         | 36. Methane, trichlorofluoro-                    | 98. Phenol, 2,4-dimethoxy-          |
| 11. Dieldrin                                                    | 37. Methane, dichlorodifluoro- (Freon-12)        | 99. $\alpha$ -Cresol, phenyl-       |
| 12. $\alpha$ -Hexachlorocyclopentadiene (Algalin)               | 38. Ethane, chloro-                              | 100. $\alpha$ -Cresol, 4,6-dinitro- |
| 13. $\beta$ -Hexachlorocyclopentadiene (Beta)                   | 39. Ethane, 1,1-dichloro-                        |                                     |
| 14. $\gamma$ -Hexachlorocyclopentadiene (Gamma)                 | 40. Ethane, 1,2-dichloro-                        |                                     |
| 15. Endrin                                                      | 41. Ethane, 1,1,1-trichloro-                     |                                     |
| 16. Endrin aldehyde                                             | 42. Ethane, 1,1,2-trichloro-                     |                                     |
| 17. Heptachlor                                                  | 43. Ethane, 1,1,2,2-tetrachloro-                 |                                     |
| 18. Heptachlor epoxide                                          | 44. Ethane, chloro- (vinyl chloride)             |                                     |
| 19. Isodrin                                                     | 45. Ethane, 1,1-dichloro-                        |                                     |
| 20. $\gamma$ -HCH                                               | 46. Ethane, 1,2-dichloro-                        |                                     |
| 21. $\delta$ -HCH                                               | 47. Ethane, 1,1,2-trichloro-                     |                                     |
| 22. $\epsilon$ -HCH                                             | 48. Ethane, 1,1,2,2-tetrachloro-                 |                                     |
| 23. $\zeta$ -HCH                                                | 49. Ethane, hexachloro-                          |                                     |
| 24. $\eta$ -HCH                                                 | 50. Ethane, chloro- (vinyl chloride)             |                                     |
| 25. $\theta$ -HCH                                               | 51. Ethane, 1,1-dichloro-                        |                                     |
| 26. $\iota$ -HCH                                                | 52. Ethane, 1,2-dichloro-                        |                                     |
| 27. $\kappa$ -HCH                                               | 53. Ethane, 1,1,2-trichloro-                     |                                     |
| 28. $\lambda$ -HCH                                              | 54. Ethane, 1,1,2,2-tetrachloro-                 |                                     |
| 29. $\mu$ -HCH                                                  | 55. Ethane, hexachloro-                          |                                     |
| 30. $\nu$ -HCH                                                  | 56. Ethane, chloro- (vinyl chloride)             |                                     |
| 31. $\xi$ -HCH                                                  | 57. Ethane, 1,1-dichloro-                        |                                     |
| 32. $\omicron$ -HCH                                             | 58. Ethane, 1,2-dichloro-                        |                                     |
| 33. $\pi$ -HCH                                                  | 59. Ethane, 1,1,2-trichloro-                     |                                     |
| 34. $\rho$ -HCH                                                 | 60. Ethane, 1,1,2,2-tetrachloro-                 |                                     |
| 35. $\sigma$ -HCH                                               | 61. Ethane, hexachloro-                          |                                     |
| 36. $\tau$ -HCH                                                 | 62. Ethane, chloro- (vinyl chloride)             |                                     |
| 37. $\upsilon$ -HCH                                             | 63. Ethane, 1,1-dichloro-                        |                                     |
| 38. $\phi$ -HCH                                                 | 64. Ethane, 1,2-dichloro-                        |                                     |
| 39. $\chi$ -HCH                                                 | 65. Ethane, 1,1,2-trichloro-                     |                                     |
| 40. $\psi$ -HCH                                                 | 66. Ethane, 1,1,2,2-tetrachloro-                 |                                     |
| 41. $\omega$ -HCH                                               | 67. Propene, 1,2-dichloro-                       |                                     |
| 42. $\alpha$ -HCH                                               | 68. Propene, 1,1-dichloro-                       |                                     |
| 43. $\beta$ -HCH                                                | 69. Butadiene, hexachloro-                       |                                     |
| 44. $\gamma$ -HCH                                               | 70. Cyclopentadiene, hexachloro-                 |                                     |
| 45. $\delta$ -HCH                                               |                                                  |                                     |
| 46. $\epsilon$ -HCH                                             |                                                  |                                     |
| 47. $\zeta$ -HCH                                                |                                                  |                                     |
| 48. $\eta$ -HCH                                                 |                                                  |                                     |
| 49. $\theta$ -HCH                                               |                                                  |                                     |
| 50. $\iota$ -HCH                                                |                                                  |                                     |
| 51. $\kappa$ -HCH                                               |                                                  |                                     |
| 52. $\lambda$ -HCH                                              |                                                  |                                     |
| 53. $\mu$ -HCH                                                  |                                                  |                                     |
| 54. $\nu$ -HCH                                                  |                                                  |                                     |
| 55. $\xi$ -HCH                                                  |                                                  |                                     |
| 56. $\omicron$ -HCH                                             |                                                  |                                     |
| 57. $\pi$ -HCH                                                  |                                                  |                                     |
| 58. $\rho$ -HCH                                                 |                                                  |                                     |
| 59. $\sigma$ -HCH                                               |                                                  |                                     |
| 60. $\tau$ -HCH                                                 |                                                  |                                     |
| 61. $\upsilon$ -HCH                                             |                                                  |                                     |
| 62. $\phi$ -HCH                                                 |                                                  |                                     |
| 63. $\chi$ -HCH                                                 |                                                  |                                     |
| 64. $\psi$ -HCH                                                 |                                                  |                                     |
| 65. $\omega$ -HCH                                               |                                                  |                                     |
| 66. $\alpha$ -HCH                                               |                                                  |                                     |
| 67. $\beta$ -HCH                                                |                                                  |                                     |
| 68. $\gamma$ -HCH                                               |                                                  |                                     |
| 69. $\delta$ -HCH                                               |                                                  |                                     |
| 70. $\epsilon$ -HCH                                             |                                                  |                                     |
| 71. $\zeta$ -HCH                                                |                                                  |                                     |
| 72. $\eta$ -HCH                                                 |                                                  |                                     |
| 73. $\theta$ -HCH                                               |                                                  |                                     |
| 74. $\iota$ -HCH                                                |                                                  |                                     |
| 75. $\kappa$ -HCH                                               |                                                  |                                     |
| 76. $\lambda$ -HCH                                              |                                                  |                                     |
| 77. $\mu$ -HCH                                                  |                                                  |                                     |
| 78. $\nu$ -HCH                                                  |                                                  |                                     |
| 79. $\xi$ -HCH                                                  |                                                  |                                     |
| 80. $\omicron$ -HCH                                             |                                                  |                                     |
| 81. $\pi$ -HCH                                                  |                                                  |                                     |
| 82. $\rho$ -HCH                                                 |                                                  |                                     |
| 83. $\sigma$ -HCH                                               |                                                  |                                     |
| 84. $\tau$ -HCH                                                 |                                                  |                                     |
| 85. $\upsilon$ -HCH                                             |                                                  |                                     |
| 86. $\phi$ -HCH                                                 |                                                  |                                     |
| 87. $\chi$ -HCH                                                 |                                                  |                                     |
| 88. $\psi$ -HCH                                                 |                                                  |                                     |
| 89. $\omega$ -HCH                                               |                                                  |                                     |
| 90. $\alpha$ -HCH                                               |                                                  |                                     |
| 91. $\beta$ -HCH                                                |                                                  |                                     |
| 92. $\gamma$ -HCH                                               |                                                  |                                     |
| 93. $\delta$ -HCH                                               |                                                  |                                     |
| 94. $\epsilon$ -HCH                                             |                                                  |                                     |
| 95. $\zeta$ -HCH                                                |                                                  |                                     |
| 96. $\eta$ -HCH                                                 |                                                  |                                     |
| 97. $\theta$ -HCH                                               |                                                  |                                     |
| 98. $\iota$ -HCH                                                |                                                  |                                     |
| 99. $\kappa$ -HCH                                               |                                                  |                                     |
| 100. $\lambda$ -HCH                                             |                                                  |                                     |
| 101. $\mu$ -HCH                                                 |                                                  |                                     |
| 102. $\nu$ -HCH                                                 |                                                  |                                     |
| 103. $\xi$ -HCH                                                 |                                                  |                                     |
| 104. $\omicron$ -HCH                                            |                                                  |                                     |
| 105. $\pi$ -HCH                                                 |                                                  |                                     |
| 106. $\rho$ -HCH                                                |                                                  |                                     |
| 107. $\sigma$ -HCH                                              |                                                  |                                     |
| 108. $\tau$ -HCH                                                |                                                  |                                     |
| 109. $\upsilon$ -HCH                                            |                                                  |                                     |
| 110. $\phi$ -HCH                                                |                                                  |                                     |
| 111. $\chi$ -HCH                                                |                                                  |                                     |
| 112. $\psi$ -HCH                                                |                                                  |                                     |
| 113. $\omega$ -HCH                                              |                                                  |                                     |
| 114. $\alpha$ -HCH                                              |                                                  |                                     |
| 115. $\beta$ -HCH                                               |                                                  |                                     |
| 116. $\gamma$ -HCH                                              |                                                  |                                     |
| 117. $\delta$ -HCH                                              |                                                  |                                     |
| 118. $\epsilon$ -HCH                                            |                                                  |                                     |
| 119. $\zeta$ -HCH                                               |                                                  |                                     |
| 120. $\eta$ -HCH                                                |                                                  |                                     |
| 121. $\theta$ -HCH                                              |                                                  |                                     |
| 122. $\iota$ -HCH                                               |                                                  |                                     |
| 123. $\kappa$ -HCH                                              |                                                  |                                     |
| 124. $\lambda$ -HCH                                             |                                                  |                                     |
| 125. $\mu$ -HCH                                                 |                                                  |                                     |
| 126. $\nu$ -HCH                                                 |                                                  |                                     |
| 127. $\xi$ -HCH                                                 |                                                  |                                     |
| 128. $\omicron$ -HCH                                            |                                                  |                                     |
| 129. $\pi$ -HCH                                                 |                                                  |                                     |
| 130. $\rho$ -HCH                                                |                                                  |                                     |
| 131. $\sigma$ -HCH                                              |                                                  |                                     |
| 132. $\tau$ -HCH                                                |                                                  |                                     |
| 133. $\upsilon$ -HCH                                            |                                                  |                                     |
| 134. $\phi$ -HCH                                                |                                                  |                                     |
| 135. $\chi$ -HCH                                                |                                                  |                                     |
| 136. $\psi$ -HCH                                                |                                                  |                                     |
| 137. $\omega$ -HCH                                              |                                                  |                                     |
| 138. $\alpha$ -HCH                                              |                                                  |                                     |
| 139. $\beta$ -HCH                                               |                                                  |                                     |
| 140. $\gamma$ -HCH                                              |                                                  |                                     |
| 141. $\delta$ -HCH                                              |                                                  |                                     |
| 142. $\epsilon$ -HCH                                            |                                                  |                                     |
| 143. $\zeta$ -HCH                                               |                                                  |                                     |
| 144. $\eta$ -HCH                                                |                                                  |                                     |
| 145. $\theta$ -HCH                                              |                                                  |                                     |
| 146. $\iota$ -HCH                                               |                                                  |                                     |
| 147. $\kappa$ -HCH                                              |                                                  |                                     |
| 148. $\lambda$ -HCH                                             |                                                  |                                     |
| 149. $\mu$ -HCH                                                 |                                                  |                                     |
| 150. $\nu$ -HCH                                                 |                                                  |                                     |
| 151. $\xi$ -HCH                                                 |                                                  |                                     |
| 152. $\omicron$ -HCH                                            |                                                  |                                     |
| 153. $\pi$ -HCH                                                 |                                                  |                                     |
| 154. $\rho$ -HCH                                                |                                                  |                                     |
| 155. $\sigma$ -HCH                                              |                                                  |                                     |
| 156. $\tau$ -HCH                                                |                                                  |                                     |
| 157. $\upsilon$ -HCH                                            |                                                  |                                     |
| 158. $\phi$ -HCH                                                |                                                  |                                     |
| 159. $\chi$ -HCH                                                |                                                  |                                     |
| 160. $\psi$ -HCH                                                |                                                  |                                     |
| 161. $\omega$ -HCH                                              |                                                  |                                     |
| 162. $\alpha$ -HCH                                              |                                                  |                                     |
| 163. $\beta$ -HCH                                               |                                                  |                                     |
| 164. $\gamma$ -HCH                                              |                                                  |                                     |
| 165. $\delta$ -HCH                                              |                                                  |                                     |
| 166. $\epsilon$ -HCH                                            |                                                  |                                     |
| 167. $\zeta$ -HCH                                               |                                                  |                                     |
| 168. $\eta$ -HCH                                                |                                                  |                                     |
| 169. $\theta$ -HCH                                              |                                                  |                                     |
| 170. $\iota$ -HCH                                               |                                                  |                                     |
| 171. $\kappa$ -HCH                                              |                                                  |                                     |
| 172. $\lambda$ -HCH                                             |                                                  |                                     |
| 173. $\mu$ -HCH                                                 |                                                  |                                     |
| 174. $\nu$ -HCH                                                 |                                                  |                                     |
| 175. $\xi$ -HCH                                                 |                                                  |                                     |
| 176. $\omicron$ -HCH                                            |                                                  |                                     |
| 177. $\pi$ -HCH                                                 |                                                  |                                     |
| 178. $\rho$ -HCH                                                |                                                  |                                     |
| 179. $\sigma$ -HCH                                              |                                                  |                                     |
| 180. $\tau$ -HCH                                                |                                                  |                                     |
| 181. $\upsilon$ -HCH                                            |                                                  |                                     |
| 182. $\phi$ -HCH                                                |                                                  |                                     |
| 183. $\chi$ -HCH                                                |                                                  |                                     |
| 184. $\psi$ -HCH                                                |                                                  |                                     |
| 185. $\omega$ -HCH                                              |                                                  |                                     |
| 186. $\alpha$ -HCH                                              |                                                  |                                     |
| 187. $\beta$ -HCH                                               |                                                  |                                     |
| 188. $\gamma$ -HCH                                              |                                                  |                                     |
| 189. $\delta$ -HCH                                              |                                                  |                                     |
| 190. $\epsilon$ -HCH                                            |                                                  |                                     |
| 191. $\zeta$ -HCH                                               |                                                  |                                     |
| 192. $\eta$ -HCH                                                |                                                  |                                     |
| 193. $\theta$ -HCH                                              |                                                  |                                     |
| 194. $\iota$ -HCH                                               |                                                  |                                     |
| 195. $\kappa$ -HCH                                              |                                                  |                                     |
| 196. $\lambda$ -HCH                                             |                                                  |                                     |
| 197. $\mu$ -HCH                                                 |                                                  |                                     |
| 198. $\nu$ -HCH                                                 |                                                  |                                     |
| 199. $\xi$ -HCH                                                 |                                                  |                                     |
| 200. $\omicron$ -HCH                                            |                                                  |                                     |
| 201. $\pi$ -HCH                                                 |                                                  |                                     |
| 202. $\rho$ -HCH                                                |                                                  |                                     |
| 203. $\sigma$ -HCH                                              |                                                  |                                     |
| 204. $\tau$ -HCH                                                |                                                  |                                     |
| 205. $\upsilon$ -HCH                                            |                                                  |                                     |
| 206. $\phi$ -HCH                                                |                                                  |                                     |
| 207. $\chi$ -HCH                                                |                                                  |                                     |
| 208. $\psi$ -HCH                                                |                                                  |                                     |
| 209. $\omega$ -HCH                                              |                                                  |                                     |
| 210. $\alpha$ -HCH                                              |                                                  |                                     |
| 211. $\beta$ -HCH                                               |                                                  |                                     |
| 212. $\gamma$ -HCH                                              |                                                  |                                     |
| 213. $\delta$ -HCH                                              |                                                  |                                     |
| 214. $\epsilon$ -HCH                                            |                                                  |                                     |
| 215. $\zeta$ -HCH                                               |                                                  |                                     |
| 216. $\eta$ -HCH                                                |                                                  |                                     |
| 217. $\theta$ -HCH                                              |                                                  |                                     |
| 218. $\iota$ -HCH                                               |                                                  |                                     |
| 219. $\kappa$ -HCH                                              |                                                  |                                     |
| 220. $\lambda$ -HCH                                             |                                                  |                                     |
| 221. $\mu$ -HCH                                                 |                                                  |                                     |
| 222. $\nu$ -HCH                                                 |                                                  |                                     |
| 223. $\xi$ -HCH                                                 |                                                  |                                     |
| 224. $\omicron$ -HCH                                            |                                                  |                                     |
| 225. $\pi$ -HCH                                                 |                                                  |                                     |
| 226. $\rho$ -HCH                                                |                                                  |                                     |
| 227. $\sigma$ -HCH                                              |                                                  |                                     |
| 228. $\tau$ -HCH                                                |                                                  |                                     |
| 229. $\upsilon$ -HCH                                            |                                                  |                                     |
| 230. $\phi$ -HCH                                                |                                                  |                                     |
| 231. $\chi$ -HCH                                                |                                                  |                                     |
| 232. $\psi$ -HCH                                                |                                                  |                                     |
| 233. $\omega$ -HCH                                              |                                                  |                                     |
| 234. $\alpha$ -HCH                                              |                                                  |                                     |
| 235. $\beta$ -HCH                                               |                                                  |                                     |
| 236. $\gamma$ -HCH                                              |                                                  |                                     |
| 237. $\delta$ -HCH                                              |                                                  |                                     |
| 238. $\epsilon$ -HCH                                            |                                                  |                                     |
| 239. $\zeta$ -HCH                                               |                                                  |                                     |
| 240. $\eta$ -HCH                                                |                                                  |                                     |
| 241. $\theta$ -HCH                                              |                                                  |                                     |
| 242. $\iota$ -HCH                                               |                                                  |                                     |
| 243. $\kappa$ -HCH                                              |                                                  |                                     |
| 244. $\lambda$ -HCH                                             |                                                  |                                     |
| 245. $\mu$ -HCH                                                 |                                                  |                                     |
| 246. $\nu$ -HCH                                                 |                                                  |                                     |
| 247. $\xi$ -HCH                                                 |                                                  |                                     |
| 248. $\omicron$ -HCH                                            |                                                  |                                     |
| 249. $\pi$ -HCH                                                 |                                                  |                                     |
| 250. $\rho$ -HCH                                                |                                                  |                                     |
| 251. $\sigma$ -HCH                                              |                                                  |                                     |
| 252. $\tau$ -HCH                                                |                                                  |                                     |
| 253. $\upsilon$ -HCH                                            |                                                  |                                     |
| 254. $\phi$ -HCH                                                |                                                  |                                     |
| 255. $\chi$ -HCH                                                |                                                  |                                     |
| 256. $\psi$ -HCH                                                |                                                  |                                     |
| 257. $\omega$ -HCH                                              |                                                  |                                     |
| 258. $\alpha$ -HCH                                              |                                                  |                                     |
| 259. $\beta$ -HCH                                               |                                                  |                                     |
| 260. $\gamma$ -HCH                                              |                                                  |                                     |
| 261. $\delta$ -HCH                                              |                                                  |                                     |
| 262. $\epsilon$ -HCH                                            |                                                  |                                     |
| 263. $\zeta$ -HCH                                               |                                                  |                                     |
| 264. $\eta$ -HCH                                                |                                                  |                                     |
| 265. $\theta$ -HCH                                              |                                                  |                                     |
| 266. $\iota$ -HCH                                               |                                                  |                                     |
| 267. $\kappa$ -HCH                                              |                                                  |                                     |
| 268. $\lambda$ -HCH                                             |                                                  |                                     |
| 269. $\mu$ -HCH                                                 |                                                  |                                     |
| 270. $\nu$ -HCH                                                 |                                                  |                                     |
| 271. $\xi$ -HCH                                                 |                                                  |                                     |
| 272. $\omicron$ -HCH                                            |                                                  |                                     |
| 273. $\pi$ -HCH                                                 |                                                  |                                     |
| 274. $\rho$ -HCH                                                |                                                  |                                     |
| 275. $\sigma$ -HCH                                              |                                                  |                                     |
| 276. $\tau$ -HCH                                                |                                                  |                                     |
| 277. $\upsilon$ -HCH                                            |                                                  |                                     |
| 278. $\phi$ -HCH                                                |                                                  |                                     |
| 279. $\chi$ -HCH                                                |                                                  |                                     |
| 280. $\psi$ -HCH                                                |                                                  |                                     |
| 281. $\omega$ -HCH                                              |                                                  |                                     |
| 282. $\alpha$ -HCH                                              |                                                  |                                     |
| 283. $\beta$ -HCH                                               |                                                  |                                     |
| 284. $\gamma$ -HCH                                              |                                                  |                                     |
| 285. $\delta$ -HCH                                              |                                                  |                                     |
| 286. $\epsilon$ -HCH                                            |                                                  |                                     |
| 287. $\zeta$ -HCH                                               |                                                  |                                     |
| 288. $\eta$ -HCH                                                |                                                  |                                     |
| 289. $\theta$ -HCH                                              |                                                  |                                     |
| 290. $\iota$ -HCH                                               |                                                  |                                     |
| 291. $\kappa$ -HCH                                              |                                                  |                                     |
| 292. $\lambda$ -HCH                                             |                                                  |                                     |
| 293. $\mu$ -HCH                                                 |                                                  |                                     |
| 294. $\nu$ -HCH                                                 |                                                  |                                     |
| 295. $\xi$ -HCH                                                 |                                                  |                                     |
| 296. $\omicron$ -HCH                                            |                                                  |                                     |
| 297. $\pi$ -HCH                                                 |                                                  |                                     |
| 298. $\rho$ -HCH                                                |                                                  |                                     |
| 299. $\sigma$ -HCH                                              |                                                  |                                     |
| 300. $\tau$ -HCH                                                |                                                  |                                     |
| 301. $\upsilon$ -HCH                                            |                                                  |                                     |
| 302. $\phi$ -HCH                                                |                                                  |                                     |
| 303. $\chi$ -HCH                                                |                                                  |                                     |
| 304. $\psi$ -HCH                                                |                                                  |                                     |
| 305. $\omega$ -HCH                                              |                                                  |                                     |
| 306. $\alpha$ -HCH                                              |                                                  |                                     |
| 307. $\beta$ -HCH                                               |                                                  |                                     |
| 308. $\gamma$ -HCH                                              |                                                  |                                     |
| 309. $\delta$ -HCH                                              |                                                  |                                     |
| 310. $\epsilon$ -HCH                                            |                                                  |                                     |
| 311. $\zeta$ -HCH                                               |                                                  |                                     |
| 312. $\eta$ -HCH                                                |                                                  |                                     |
| 313. $\theta$ -HCH                                              |                                                  |                                     |
| 314. $\iota$ -HCH                                               |                                                  |                                     |
| 315. $\kappa$ -HCH                                              |                                                  |                                     |
| 316. $\lambda$ -HCH                                             |                                                  |                                     |
| 317. $\mu$ -HCH                                                 |                                                  |                                     |
| 318. $\nu$ -HCH                                                 |                                                  |                                     |
| 319. $\xi$ -HCH                                                 |                                                  |                                     |
| 320. $\omicron$ -HCH                                            |                                                  |                                     |
| 321. $\pi$ -HCH                                                 |                                                  |                                     |
| 322. $\rho$ -HCH                                                |                                                  |                                     |
| 323. $\sigma$ -HCH                                              |                                                  |                                     |
| 324. $\tau$ -HCH                                                |                                                  |                                     |
| 325. $\upsilon$ -HCH                                            |                                                  |                                     |
| 326. $\phi$ -HCH                                                |                                                  |                                     |
| 327. $\chi$ -HCH                                                |                                                  |                                     |
| 328. $\psi$ -HCH                                                |                                                  |                                     |
| 329. $\omega$ -HCH                                              |                                                  |                                     |
| 330. $\alpha$ -HCH                                              |                                                  |                                     |
| 331. $\beta$ -HCH                                               |                                                  |                                     |
| 332. $\gamma$ -HCH                                              |                                                  |                                     |
| 333. $\delta$ -HCH                                              |                                                  |                                     |
| 334. $\epsilon$ -HCH                                            |                                                  |                                     |
| 335. $\zeta$ -HCH                                               |                                                  |                                     |
| 336. $\eta$ -HCH                                                |                                                  |                                     |
| 337. $\theta$ -HCH                                              |                                                  |                                     |
| 338. $\iota$ -HCH                                               |                                                  |                                     |
| 339. $\kappa$ -HCH                                              |                                                  |                                     |
| 340. $\lambda$ -HCH                                             |                                                  |                                     |
| 341. $\mu$ -HCH                                                 |                                                  |                                     |
| 342. $\nu$ -HCH                                                 |                                                  |                                     |
| 343. $\xi$ -HCH                                                 |                                                  |                                     |
| 344. $\omicron$ -HCH                                            |                                                  |                                     |
| 345. $\pi$ -HCH                                                 |                                                  |                                     |
| 346. $\rho$ -HCH                                                |                                                  |                                     |
| 347. $\sigma$ -HCH                                              |                                                  |                                     |
| 348. $\tau$ -HCH                                                |                                                  |                                     |
| 349. $\upsilon$ -HCH                                            |                                                  |                                     |
| 350. $\phi$ -HCH                                                |                                                  |                                     |
| 351. $\chi$ -HCH                                                |                                                  |                                     |
| 352. $\psi$ -HCH                                                |                                                  |                                     |
| 353. $\omega$ -HCH                                              |                                                  |                                     |
| 354. $\alpha$ -HCH                                              |                                                  |                                     |
| 355. $\beta$ -HCH                                               |                                                  |                                     |
| 356. $\gamma$ -HCH                                              |                                                  |                                     |
| 357. $\delta$ -HCH                                              |                                                  |                                     |
| 358. $\epsilon$ -HCH                                            |                                                  |                                     |
| 359. $\zeta$ -HCH                                               |                                                  |                                     |
| 360. $\eta$ -HCH                                                |                                                  |                                     |
| 361. $\theta$ -HCH                                              |                                                  |                                     |
| 362. $\iota$ -HCH                                               |                                                  |                                     |
| 363. $\kappa$ -HCH                                              |                                                  |                                     |
| 364. $\lambda$ -HCH                                             |                                                  |                                     |
| 365. $\mu$ -HCH                                                 |                                                  |                                     |
| 366. $\nu$ -HCH</                                               |                                                  |                                     |

## PRIORITY POLLUTANT SCAN

In recent years, there has been a growing public concern over the presence of toxic chemicals in the environment, particularly in water supplies. Since urban runoff is often a component of the overall water supply in many developing communities, questions have been raised as to the nature and toxicity of pollutants entrained in urban runoff. One of the major objectives of the EPA NURP program was to evaluate the significance of this risk. To this end, EPA conducted a National Priority Pollutant Monitoring Program on the runoff from 19 urban areas throughout the country. Runoff samples were analyzed to detect the presence of 128 priority pollutants, designated under Section 207 of the Clean Water Act. A comprehensive list of these pollutants is provided in Table 5.1. As can be seen, ten major groups of toxic chemicals were represented, including pesticides, trace metals, PCB's and organic compounds.

The Washington area priority pollutant scan was performed by JTC Environmental Consultants, Inc., under contract with MWCOG. Flow-composited urban runoff samples were collected at BMP monitoring stations during storm events by OWML field personnel and delivered to JTC labs for subsequent analysis on a gas chromatograph/mass spectrometer. The sample collection effort was designed to determine the presence of toxicants in urban runoff and sediments from five general areas within the suburban drainage system:

- Runoff entering stormwater ponds from small, single land use watersheds (5 sites)
- Runoff leaving from infiltration-type BMP structure (for example, grassed swales and porous pavements - 5 sites)
- Ponded water within stormwater basins (2 sites)
- Bottom sediments of wet stormwater ponds (3 sites)
- Free-flowing waters of larger receiving streams (1 site)

Because of the high cost of laboratory analysis (approximately \$750 per sample) it was only feasible to collect one sample at each site. Therefore, the priority pollutant data only provides a single snapshot of toxicant conditions at one point and time. As such, the data can only be interpreted in a rather limited context, i.e., providing more of an initial screening assessment of the possible presence of toxicants in the urban environment rather than a final evaluation of toxicant risks.

### Results of the Priority Pollutant Scan

Of the 128 priority pollutants listed by EPA, only 28 (or 21 percent) were discovered in any of the Washington urban runoff samples. Ten of the priority pollutants detected were pesticides, 12 were trace metals, 3 were phenols and the remainder were assorted organic compounds.

Pesticides which were detected at trace levels included aldrin, lindane, BHC, endosulfan, DDT and Heptachlor. It should be noted that the concentrations of these pesticides were extremely low (less than 0.1 parts per billion - ppb) and were at the limits of detectability. Most of the pesticides detected were



Table 5.2  
PRIORITY POLLUTANTS DETECTED IN WASHINGTON AREA  
URBAN RUNOFF SAMPLES

| DETECTED<br>PRIORITY<br>POLLUTANT | MAXIMUM<br>REPORTED<br>CONCENTRATION | AVERAGE<br>CONCENTRATION | FREQUENCY<br>OF<br>DETECTION | WATER QUALITY<br>CRITERIA EXCEEDANCES |    |     |     |     |
|-----------------------------------|--------------------------------------|--------------------------|------------------------------|---------------------------------------|----|-----|-----|-----|
|                                   |                                      |                          |                              | FA                                    | OL | HM  | HC  | CU  |
| Aldrin                            | <0.1                                 | <0.1                     | 24                           |                                       |    |     |     |     |
| alpha-BHC                         | 3.1                                  | <0.1                     | 55                           | 02                                    |    |     | 24% | 02  |
| beta-BHC                          | 0.1                                  | <0.1                     | 41                           |                                       |    |     | 02  |     |
| delta-BHC                         | 0.2                                  | <0.1                     | 47                           |                                       |    |     | 02  |     |
| Lindane                           | <0.1                                 | <0.1                     | 41                           |                                       |    |     |     |     |
| DUT                               | <0.1                                 | <0.1                     | 5                            | 02                                    |    |     | 02  | 02  |
| Endosulfa                         | 3.1                                  | <0.1                     | 24                           | 02                                    |    | 02  |     | 02  |
| Heptachlor                        | 0.1                                  | <0.1                     | 15                           | 02                                    |    | 02  |     | 02  |
| Heptachlor expox.                 | <0.1                                 | <0.1                     | 5                            | 02                                    |    |     |     | 02  |
| Ispnalone                         | <10                                  | <10                      | 5                            | 02                                    |    |     |     | 02  |
| Antimony                          | 9                                    | 2.5                      | 24                           | 02                                    |    | 02  |     | 02  |
| Arsenic                           | 30                                   | 5.5                      | 33                           | 02                                    |    | 02  |     | 02  |
| Beryllium                         | 49                                   | 14.6                     | 33                           | 02                                    |    | 72  | 12% | 72  |
| Cadmium                           | 3                                    | 0.7                      | 40                           | 02                                    |    | 02  | 02  | 02  |
| Chromium                          | 20                                   | 4.9                      | 67                           | 02                                    |    | 02  |     | 02  |
| Copper                            | 50                                   | 13.                      | 40                           | 02                                    |    | 02  |     | 02  |
| Lead                              | 38                                   | 14.1                     | 33                           | 02                                    |    | 02  |     | 02  |
| Mercury                           | 0.3                                  | 0.2                      | 33                           | 02                                    |    | 02  |     | 02  |
| Nickel                            | 119                                  | 37.2                     | 33                           | 02                                    |    |     | 12% | 02  |
| Selenium                          | 77                                   | 22.1                     | 47                           | 02                                    |    | 40% | 12% | 02  |
| Thallium                          | 14                                   | 2.73                     | 40                           | 02                                    |    | 47% |     | 47% |
| Zinc                              | 500                                  | 30.3                     | 73                           | 02                                    |    | 12% |     | 02  |
| Ethane 1,1,1-trichloro            | <10                                  | <10                      | 29                           | 02                                    |    |     |     | 02  |
| Benzene-chloro                    | <10                                  | <10                      | 52                           | 02                                    |    | 02  |     | 02  |
| Phenol                            | <10                                  | <10                      | 12%                          | 02                                    |    | 02  |     | 02  |
| Phenol, 4-nitro                   | <10                                  | <10                      | 52                           | 02                                    |    | 02  |     | 02  |
| Phenol, 2,4 dimethyl              | <10                                  | <10                      | 52                           | 02                                    |    |     |     | 02  |
| Chrysene                          | <10                                  | <10                      | 52                           | 02                                    |    |     |     | 02  |

NOTES: FA = Freshwater Aquatic Life Protection Criteria; ambient 24 hour instantaneous maximum (aka-"Acute").  
Assuming 100 mg/l of hardness.

OL = Organoleptic: Taste and Odor Criteria

HM = Non-carcinogenic human health criteria for daily ingestion of 2 liters contaminated water  
and 5.5 grams of contaminated fish

HC = Carcinogenic human health criteria from ingestion of contaminated water and organisms, one  
additional case of cancer per 100,000 people exposed.

CU = Primary Drinking Water Standards

• = No criteria, or no criteria published to date.

• = Welfare criteria

• = Denotes a violation of chronic freshwater aquatic life criteria, 24 hour average concentration (see text)

SOURCE: Appendix 3. National WURP Priority Pollutant Monitoring Program. Volume 1: Findings.  
1983 Dalton-Dalton-Newport

insecticides, and many were probably derived from applications to control garden and home insects. As can be seen in Table 5.2, reported levels of these pesticides pose little or no risk to human health or aquatic life according to established EPA water quality criteria. The only reported violation was the human health criteria for carcinogenicity in the case of aldrin. The applicability of this criteria is questionable, as it presumes a daily intake of 2.2 liters of urban runoff and 6.5 grams of contaminated fish tissue to produce one extra case of cancer per 100,000 individuals. The degree to which such consumption occurs in urban areas is obviously quite limited. Probably the most important conclusion to be drawn from the pesticide data is that it suggests an apparent linkage between insecticide application and its presence in urban runoff.

The priority pollutants which were consistently detected in the greatest frequency and at the highest concentrations were the trace metals. This data is presented in Table 5.3. Of the 13 trace metals analyzed, only one, silver, was not detected in any of the samples collected. The other 12 trace metals were detected with frequencies ranging from 33 to 93 percent of all samples. Concentrations of four metals tended to be particularly high -- zinc, copper, lead and nickel. Collectively, 9 trace metals violated one or more of four EPA water quality criteria (acute freshwater aquatic life protection, human health-carcinogenic, human health-noncarcinogenic, and drinking water criteria). Taste and odor criteria apparently were never violated. Additionally, seven trace metals were detected at levels above the freshwater aquatic life criteria for 24 hour chronic exposure. However, it should be noted that since urban runoff events seldom extend past 6 to 8 hours, such violations are rather unlikely to occur. (Dalton, Dalton and Newport, 1983)

The implications of the observed trace metal criteria violations are difficult to assess (Table 5.2). As noted earlier, the two human health criteria (carcinogenic and non-carcinogenic) are dependent upon actual ingestion of water and contaminated fish products. Obviously, these activities are the exception rather than the rule since untreated urban runoff is certainly not appealing to drink, and fishing activities within local urban streams are generally quite limited. The potential impact of drinking water criteria violations may be more significant; however, exposure in most instances is probably greater reduced by dilution processes, as well as the filtering of water supplies. Similarly, the significance of trace metal violations of aquatic life criteria is not well understood at present. Dilution may reduce exposure to the extent that trace metal concentrations fall below aquatic life criteria levels. However, a final determination of the seriousness of observed trace metal levels awaits bioassay, fish tissue or microcosm research.

The remaining priority pollutants detected in the urban runoff samples included a halogenated aliphatic, a monocyclic aromatic, three phenol derivatives and a polycyclic aromatic hydrocarbon. These compounds were only found in small percentage of samples, were less than 10 ppb, and did not exceed important water quality criteria levels.

Of significant interest were the 100 priority pollutants which were not detected in urban runoff. Some of the more notable compounds which were not found included PCBs, chloroform, benzene, toluene, creosols, phthalates and nitrosamines. The absence of these toxicants in the runoff of the largely residential watersheds analyzed in the Washington priority pollutant scan was not all together surprising, since many of them are normally derived from industrial sources.

Table 5.3  
TRACE METALS DETECTED IN URBAN RUNOFF TOXICANT SCAN

|                                                    | Silver<br>Ag | Arsenic<br>As | Beryllium<br>Be | Cadmium<br>Cd | Chromium<br>Cr | Copper<br>Cu | Mercury<br>Hg | Nickel<br>Ni | Lead<br>Pb | Antimony<br>Sb | Selenium<br>Se | Thallium<br>Tl | Zinc<br>Zn |
|----------------------------------------------------|--------------|---------------|-----------------|---------------|----------------|--------------|---------------|--------------|------------|----------------|----------------|----------------|------------|
| All units in parts per billion                     |              |               |                 |               |                |              |               |              |            |                |                |                |            |
| <u>RUNOFF SAMPLES ENTERING PUMPS</u>               |              |               |                 |               |                |              |               |              |            |                |                |                |            |
| UP Burke (UR-3)                                    | ND           | 1             | ND              | 1             | 10             | 6            | ND            | 65           | 18         | ND             | ND             | ND             | 42         |
| UP Lakeridge (UR-7)                                | ND           | 50*           | 1               | 1             | 6              | 50*          | 0.6           | 8            | 7          | 3              | 17*            | ND             | 600        |
| EDP Steadick (UR-10)                               | ND           | ND            | 35              | 1             | 3              | 7            | ND            | 50           | 20         | 8              | 59*            | 14             | 136        |
| UP Bulk Hall (UR-13)                               | ND           | 3             | 49              | 3             | 16             | 46           | 0.5           | 37           | 26         | ND             | 24*            | 5              | 122        |
| UP Westleigh (UR-15)                               | ND           | 43            | 1               | 2             | 20             | 60*          | 0.8           | 16           | 30         | 3              | 17*            | ND             | ND         |
| <u>RUNOFF SAMPLES EXITING INFILTRATION DEVICES</u> |              |               |                 |               |                |              |               |              |            |                |                |                |            |
| GS Bandridge (UR-5)                                | ND           | ND            | 35              | ND            | ND             | 2            | 0.6           | 44           | 10         | ND             | 68*            | 1              | ND         |
| GS Stratton Woods (UR-6)                           | ND           | ND            | 20              | ND            | ND             | 2            | 0.6           | 119          | 17         | 9              | 40*            | 8              | 25         |
| GS Fair Ridge (UR-9)                               | ND           | ND            | 44              | ND            | 2              | 5            | ND            | 108          | 20         | 7              | 30*            | 8              | 21         |
| UP Burke Village (UR-17)                           | ND           | 2             | ND              | 1             | 10             | 13           | ND            | 1            | 18         | ND             | ND             | ND             | 42         |
| UP Rockville (UR-19)                               | ND           | ND            | 34              | ND            | ND             | 1            | ND            | 65           | 18         | ND             | 77*            | 5              | ND         |
| <u>STORMWATER POND WATER</u>                       |              |               |                 |               |                |              |               |              |            |                |                |                |            |
| UP Lakeridge (UR-7)                                | ND           | ND            | ND              | ND            | 3              | 1            | ND            | 5            | 8          | ND             | ND             | ND             | 26         |
| UP Westleigh (UR-15)                               | ND           | ND            | ND              | ND            | 2              | ND           | ND            | ND           | ND         | ND             | ND             | ND             | 15         |
| <u>STORMWATER POND SEDIMENTS</u>                   |              |               |                 |               |                |              |               |              |            |                |                |                |            |
| UP Burke (UR-3)                                    | ND           | ND            | ND              | ND            | ND             | ND           | ND            | 8            | 1          | ND             | ND             | ND             | ND         |
| UP Westleigh (UR-15)                               | ND           | ND            | ND              | ND            | ND             | ND           | ND            | 32           | 1          | ND             | ND             | ND             | ND         |
| <u>FREE-FLOWING STREAM</u>                         |              |               |                 |               |                |              |               |              |            |                |                |                |            |
| - Little Seneca Creek                              | ND           | ND            | ND              | ND            | 2              | 3            | ND            | ND           | 2          | ND             | ND             | ND             | 34         |
| Typical Detection Limits                           | 0.5          | 0.5           | 0.2             | 0.1           | 1.0            | 1.0          | 0.2           | 1.0          | 1.0        | 3.0            | 2.0            | 1.0            | 5.0        |
| Average Concentration                              | <0.5         | 6.6           | 14.6            | 0.7           | 4.9            | 13.0         | 0.2           | 37.2         | 14.1       | 2.5            | 22.1           | 2.73           | 90.9       |
| Frequency of Detection (%)                         | 0            | 33            | 53              | 40            | 67             | 80           | 33            | 87           | 93         | 33             | 47             | 40             | 73         |
| Aquatic Life Standards                             | -            | 440           | NCA             | 3.0           | 4700           | 22           | 4.1           | 1800         | 170        | NCA            | 260            | 1400           | 320        |
| Drinking Water Standards                           | 50           | 50            | NA              | 10            | 50             | 50           | 2             | NA           | 50         | NA             | 10             | NA             | NA         |

ND = Not detected

NCA = No criteria available

\* = Violation of drinking water standards

In summary, with the possible exception of some trace metals (such as cadmium, copper, nickel and selenium), the majority of the priority pollutants monitored were either not detected or were present at such low levels as to pose little or no risk to humans or aquatic life. This conclusion, however, should be considered preliminary due to the very limited number of runoff samples analyzed. Also, this conclusion should be further tempered given the general lack of knowledge concerning possible environmental effects of toxicant accumulation in the sediments.

A complete summary of the analytical results of the priority pollutant scan, along with a review of laboratory methods and quality assurance/control procedures is included in the November 1982 Final Report on Priority Pollutant Analysis prepared by JTC Environmental Consultants and available from MWCOG/DEP.

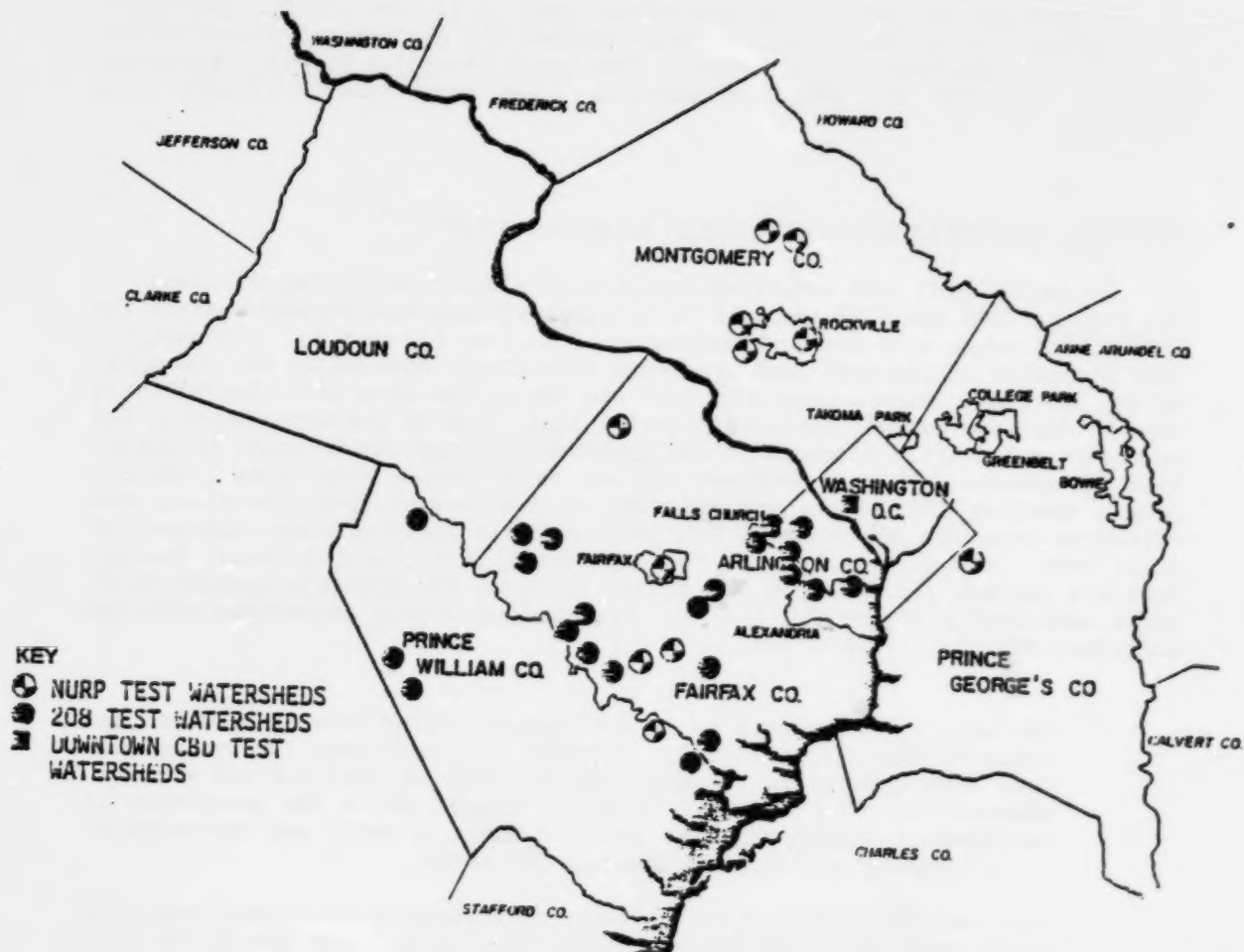
### CENTRAL BUSINESS DISTRICT (CBD) LOADING STUDY

Of the 33 small test watersheds collectively monitored during the course of the regional 208 and NURP nonpoint field studies, none were situated inside the traditional urban core areas of Washington, D.C. (see Figure 5.1). Although the full diversity of regional land uses were effectively covered by the two monitoring programs, certain specific land use variations were not. One of these was the downtown central business district zone. Due to the differences in development and traffic patterns it was hypothesized that the nonpoint pollutant loadings generated from a downtown CBD may be different from those generated from a suburban CBD. These suburban CBD rates were developed from field data collected under the 208 study (NVPDC, 1979). If the hypothesis was supported by field data, it would necessitate the adjustment of regional nonpoint loading land use factors for downtown CBD areas. Some of the possible factors which could conceivably affect CBD loading rates between highly impervious suburban and urban CBDs are listed below:

- The nature and patterns of imperviousness differ between suburban and downtown CBDs. Specifically, downtown CBDs have less impervious surface area devoted to parking lots and more to rooftops and streets, compared to suburban CBDs. This is largely due to the prevalence of underground parking (in some cases, transit as well) and the presence of multi-story buildings in downtown CBD areas.
- Downtown CBDs usually have a greater percentage of impervious area than their suburban counterparts. Since space is at a premium in the more intensively developed downtown CBDs, the percentage of impervious area often approaches 100 percent. In contrast, the less intensively developed suburban CBD's usually are slightly less impervious, typically on the order of 90 to 95 percent.
- Traffic volumes in downtown CBD's are often greater than suburban CBD's, on a vehicle/day/unit area basis. Also, streets and alleys often comprise a greater proportion of total area in downtown CBD's.
- Atmospheric deposition rates appear to exhibit significant differences between urban and suburban areas in the Washington area (Chapter 4).



Figure 5.1  
REGIONAL LOCATIONS OF SMALL TEST WATERSHEDS USED TO  
DEVELOP NONPOINT LOADING RATES: NURP AND 208 STUDIES



To test the hypothesis, runoff monitored at two sites located in the downtown Washington, D.C. CBD as part of the District of Columbia's Combined Sewer Overflow Study (O'Brien and Gere 1983), was compared to runoff data from a suburban CBD site monitored during the 208 study (NVPDC, 1979). As can be seen in Table 5.4, most of the comparative factors cited earlier which could conceivably affect the rate of nonpoint pollutant generation were evident in the downtown and suburban catchments monitored.

The monitoring and analytical procedures employed in each runoff sampling effort are described in NVPDC (1981). Both the downtown and suburban CBDs were instrumented with automated samplers and flow meters within storm sewers, which collected sequential discrete runoff samples. 14 storm events were monitored at the suburban CBD, compared to 16 at the downtown sites. Apart from the relatively small number of storm events sampled, there were numerous monitoring problems which significantly hampered the extent to which the two data sets could be compared. Flow metering equipment installed at the downtown site repeatedly malfunctioned, and as a result, flow data was only reported for one storm event. The practical implication of this problem was that downtown non-point loadings could not be estimated. Thus, the only basis of comparison between the downtown and suburban CBD sites was the average concentration of pollutants over the sampling intervals. While generally informative, comparisons of average concentrations have limited value, since they assume that all storms are of equal intensity and volume. Given these and other inherent monitoring deficiencies, it was felt that the data set was insufficient to test the hypothesis.

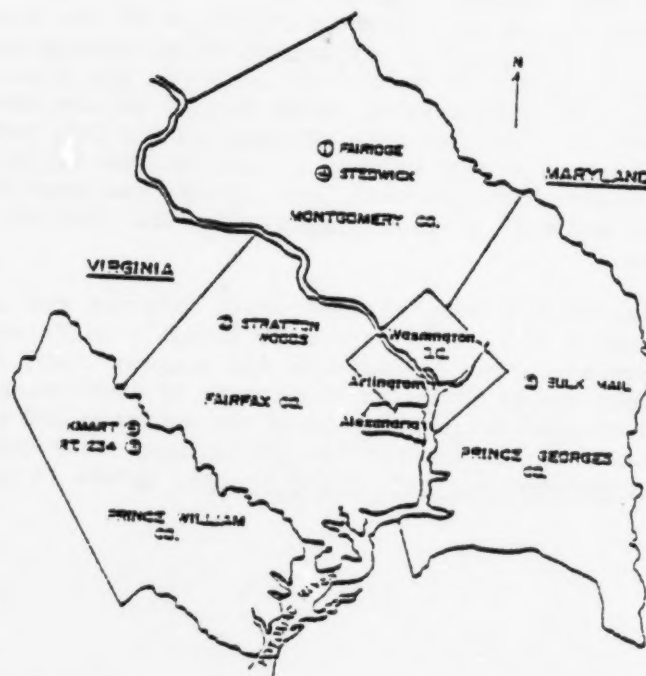
The comparisons of average pollutant concentrations were, nevertheless, interesting. Contrary to expectation, the average concentration of sediment, total nitrogen, lead and zinc were somewhat higher at the suburban site than the combined downtown sites. However, in all cases, the average concentration at the downtown site was within one standard deviation of the mean suburban site concentration. On the other hand, oxygen-demanding substances were slightly higher at the downtown site. Of particular note was the finding that soluble phosphorus concentrations were several times higher at the downtown CBD site than at the suburban site. No immediate explanation for this rather curious result is offered. Comparisons of average concentrations of pollutants in the runoff of downtown or suburban CBDs with less intense residential land uses sampled in both the 208 and NURP studies suggest that CBD loadings are the highest of any local land use.

In summary, insufficient comparative runoff data was available to test the hypothesis that downtown CBD loads were significantly different from suburban CBD. The average concentration comparisons did suggest that, for most parameters, pollutant levels are of a similar magnitude, in downtown and suburban CBDs with a trend toward slightly higher levels at the suburban CBD site for some parameters. More details on the comparative CBD loading study can be found in the Appendix III, of the Washington Interim NURP Report, Volume II (MWCOC, 1981).

Table 5.4  
COMPARISON OF SUBURBAN AND DOWNTOWN CENTRAL BUSINESS  
DISTRICT CATCHMENTS

|                                            | SIZE<br>(Acres) | EFFECTIVE<br>IMPERVIOUSNESS<br>(%) | STREETS AS<br>PERCENT OF<br>WATERSHED AREA<br>(%) | ROOFTOPS AS<br>PERCENT OF<br>WATERSHED AREA<br>(%) | CURB<br>LENGTH<br>ft/acre | TRAFFIC<br>VOLUME<br>Vehicles/Day/Acre |
|--------------------------------------------|-----------------|------------------------------------|---------------------------------------------------|----------------------------------------------------|---------------------------|----------------------------------------|
| SUBURBAN CBD<br>PARKINGTON<br>(208 STUDY)  | 25              | 95                                 | 20                                                | 33                                                 | 310                       | ~2500                                  |
| DOWNTOWN CBD<br>DC SITES 102/103<br>(NURP) | 7.1             | 99                                 | 27                                                | 48                                                 | 375                       | ~7500                                  |

Figure 5.2  
LOCATION OF SOIL METAL BMP SAMPLING SITES IN THE  
WASHINGTON METROPOLITAN AREA



## TRACE METAL ACCUMULATION AND MOVEMENT IN URBAN BMPs

The relative soil concentrations of cadmium, copper, lead and zinc were measured in the soils within and adjacent to grassed swales and stormwater pond at six sites throughout the Washington region (Figure 5.2). This monitoring study had three primary objectives. The first was to assess whether or not these trace metals were accumulating within BMPs. This was done to determine whether or not the BMPs effectively removed trace metals entrained in urban runoff. A second objective was to determine the magnitude and variability of trace metals within BMP sediments. Particular emphasis was placed on evaluating the environmental risks from trace metal accumulation from the standpoint of disposal of dredged sediments in stormwater ponds. The last objective was to track the movement of trace metals through the soil profile so as to evaluate the potential risk of trace metals leaching into groundwater supplies.

The major elements of the sampling design can be seen in Figure 5.3. At each grassed swale, surface soil plugs were collected on a cross-section across the swale, which was divided into a road, swale and yard zone (Panel A). Ten such cross-sections were sampled at each swale drain, and 20 swales were sampled within each residential swale system (Panel B). Trace metal depth sampling was conducted at the lower end of selected swale drains using a bucket auger to collect 60 centimeters soil cores. Stormwater ponds were sampled by retrieving surface soil plugs and depth cores within and adjacent to the basin, along a well-defined sampling matrix (Panel C). Sample metal concentrations were then determined by direct aspiration in an Atomic Absorption Spectrophotometer.

### Grassed Swales

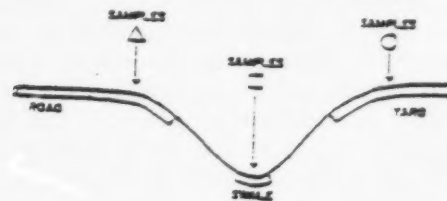
Theoretically, soil trace metal concentration should be expected to progressively decline with increasing distance from the road (the dominant source of metals). (OWML, 1983) If this gradient in trace metal concentration is interrupted (i.e., trace metal concentrations are higher in the swale than in the road), then a strong case for accumulation of metals within the swale can be made. Evidence of the accumulation of trace metals within the swale, in turn, provides presumptive evidence of pollutant removal capability.

To test this hypothesis, the road/swale/yard soil metal gradients determined at each grassed swale site were evaluated by various statistical techniques (described in Chapter 11, OWML, 1983). This analysis indicated that zinc and cadmium had accumulated within the soils of the three grassed swale sites monitored. The rate of soil enrichment of zinc ranged from 16 to 22 parts per million-(ppm)/year, while cadmium accumulated in the soil at an maximum annual rate of 0.02 ppm. Lead followed a consistent declining gradient which indicated no accumulation had occurred. Generally similar, but somewhat more variable results were obtained for copper.

Closer analysis of the spatial distribution of soil metal levels suggested that road sources of metals probably did not produce the accumulation of zinc and cadmium. Soil metal concentrations were found to vary inversely in relationship to the downslope distance from drainage galvanized culverts (Figure 5.4). This pattern, which was most pronounced for zinc, suggested that the galvanized driveway culverts which connected successive swales were a significant source of the observed metals. Linear regression models based on the soil metals data indicated that galvanized culverts could account for as much as 30 to 200 ppm of the elevated zinc levels and up to 0.10 ppm of the cadmium increase.

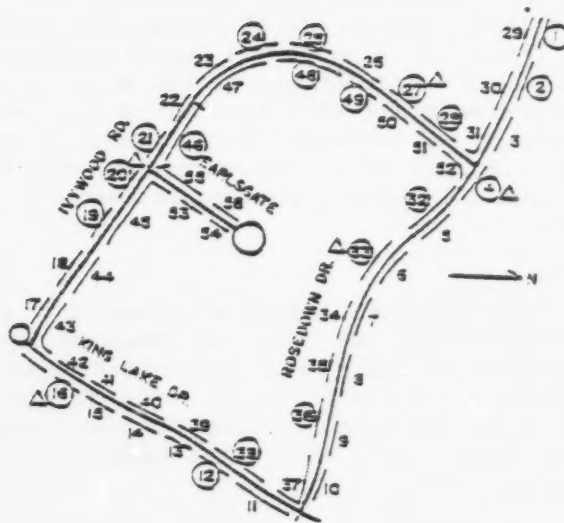


Figure 5.3  
SAMPLING PROTOCOLS EMPLOYED IN SOIL METAL STUDY



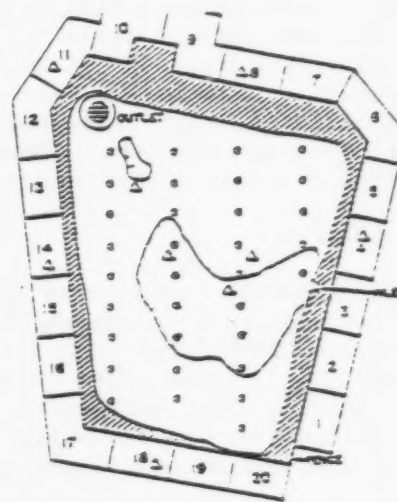
PANEL A

Sampling Cross-Section Across Grassed Swale



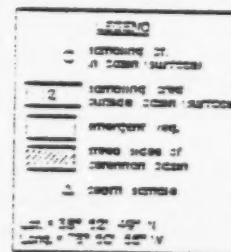
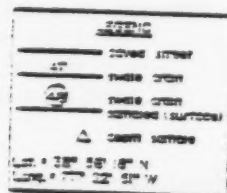
PANEL B

Sampling Design in Residential Swale System



PANEL C

Soil Metal Sampling Layout in Stormwater Pond



(CWML, 1983) Acid rain within the region appears to be the causative agent in this case (Chapter 4). Although the pH of swale runoff quickly reaches neutrality, there appears to be sufficient contact of the acid runoff with galvanized culverts to "desorb" or release trace metals impurities from the pipes.

Soil metal core sampling within the grassed swales revealed a pattern of rapidly declining soil metal concentrations with increasing soil depth. The highest swale concentrations were in the top 5 cm of soil, and beyond 15 to 30 cm soil metal concentrations remained constant or became asymptotic with zero. This pattern of trace metal distribution in the soil provides rather strong evidence that downward leaching of soil metals is not a serious problem in grassed swales.

### Stormwater Basins

As in the case of grassed swales, the presence of significantly greater soil metal concentrations within the stormwater basins relative to adjacent control sites was taken as presumptive evidence of metal accumulation within the BMP. Statistical analysis demonstrated that significant accumulations of cadmium, copper, lead and zinc had occurred in the soils at all of the three ponds monitored. Lead and zinc exhibited the greatest net accumulation, relative to their control, while copper and cadmium experienced only moderate increases. The spatial component of these general accumulation patterns are illustrated in the series of iso-concentration maps of the Bulk Mail detention pond (Figure 5.5). The watershed serviced by this BMP was primarily comprised of an actively used parking lot for heavy trucks. As the presence of metals are very closely related to the vehicular traffic, (Helsel, et al, 1981) it is not surprising to find that the Bulk Mail pond had the greatest accumulation of zinc, cadmium and copper of the three stormwater basins studied (as well as the second highest lead concentration). In all three basins, the highest soil metal accumulation was closely associated with areas within the pond which tend to have the most backed-up or standing water.

Maximum soil metal accumulation rates within the three stormwater basins were 0.4 ppm/yr for cadmium, 2.7 ppm/yr for copper, 61.4 ppm/yr for lead and 32 ppm/yr for zinc. Taken together, this data suggest that a high degree of trace metal removal took place with the basins. The high trace metal removal rates noted in the two "dry" stormwater ponds (Bulk Mail and K-Mart) is somewhat surprising in light of the relatively poor trace metal removal capability attributed to conventional dry basins (Chapter 2). However, these two ponds effectively act as extended detention basins since the outlets were often clogged to the extent that natural wetlands became well established in the pond.

The results of the soil metal depth sampling study in the stormwater basins also provided substantial evidence that little or no downward leaching of soil metals had occurred at any of the three sites, even though surface soil metal concentrations were quite high. Based on these findings, it would appear that leaching of trace metals into the groundwater should not be a serious problem in most stormwater basins.

A potential consequence of the high trace metal levels in the surface soils of stormwater ponds is that they may present a problem with respect to disposal of pond sediments (which are periodically dredged as part of pond maintenance). Although the volume of dredged stormwater basin sediments is very small in comparison to the volume of sludge generated at municipal treatment plants, trace

Figure 5.4  
RELATIONSHIP BETWEEN ZINC CONCENTRATION IN RUNOFF AND  
DOWNSTREAM DISTANCE FROM CULVERT OUTLET AT TWO  
GRASSED SWALE SITES

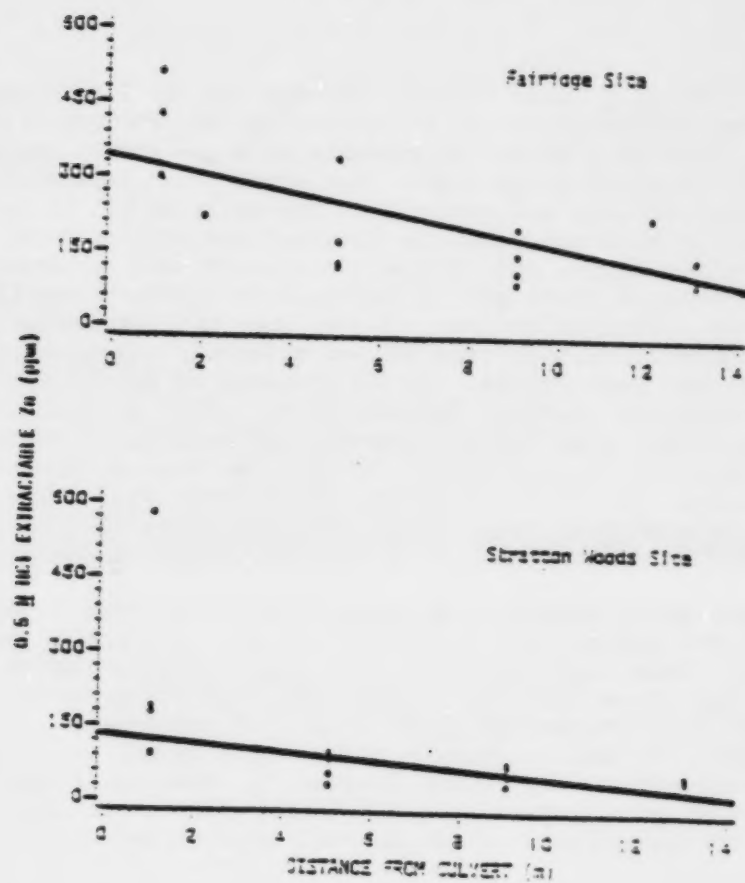
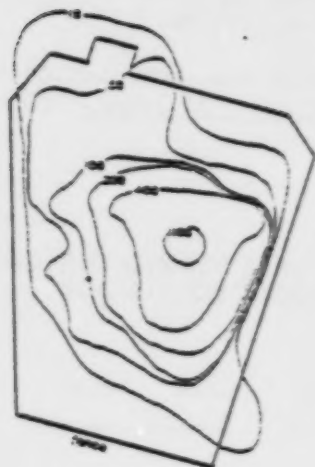
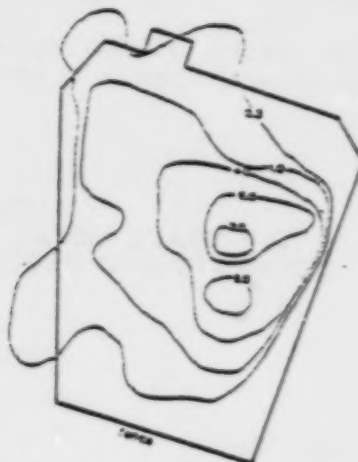


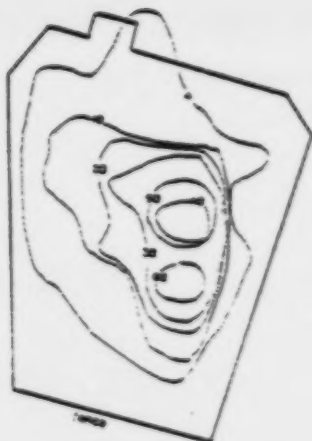
Figure 5.5  
ISO-CONCENTRATION MAPS OF TRACE METAL DISTRIBUTIONS  
IN THE SEDIMENTS OF THE BULK MAIL STORMWATER POND



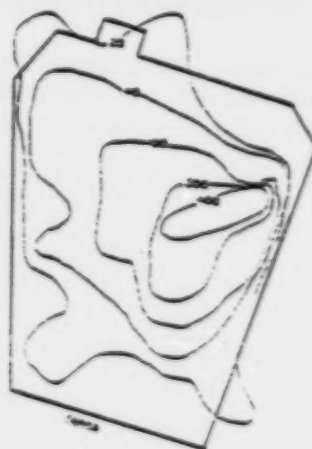
Surface soil 0.5 g HCl extractable Pb (concentration  
100 (2000), Bulk Mail Stormwater Pond site



Surface soil 0.5 g HCl extractable Cd (concentration  
100 (2000), Bulk Mail Stormwater Pond site



Surface soil 0.5 g HCl extractable Cu (concentration  
100 (2000), Bulk Mail Stormwater Pond site



Surface soil 0.5 g HCl extractable Zn (concentration  
100 (2000), Bulk Mail Stormwater Pond site



metal contamination of stormwater sediments could conceivably raise the O&M costs associated with stormwater ponds maintenance (MWCOG, April 1983). Table 5.5 presents comparison of the maximum reported stormwater basin soil metal levels with median metal content of Washington area municipal treatment plant sludge. As can be seen, trace metal levels in sludge are generally higher than those observed in stormwater basin sediments. Since local composted sludge is considered to pose no appreciable environmental risk from the standpoint of land application (Chaney, 1980), it follows that disposal of stormwater basin sediments should also not be a significant environmental problem.

The entire results of the soil metal movement and accumulation study are thoroughly described in Chapter 10 of the VPI&SU Final NURP Report (OWML, 1983).

Table 5.5  
COMPARATIVE TRACE METAL CONTENT OF STORMWATER BASIN  
SEDIMENTS AND REGIONALLY PRODUCED SLUDGE

|                                                                  | Cadmium | Copper<br>ppm | Lead | Zinc |
|------------------------------------------------------------------|---------|---------------|------|------|
| Maximum, Soil<br>Metal Level in<br>Stormwater Ponds              | 12      | 140           | 400  | 1100 |
| Median Concentration<br>of Soil Metals in<br>Area STP sludge (1) | 13      | 800           | 500  | 1700 |

(1) Source. R. Chaney, 1980. Sludge Management: Risk Assessment for Plant and Animal Life.

## BIOAVAILABILITY OF NUTRIENTS IN URBAN RUNOFF

Although the subject of nutrient generation and transport in urban stormwaters has been extensively studied in recent years, little research has been done on the relative availability of these nutrients in biological systems. This aspect of urban runoff research is extremely important because the biological consequences of nutrients are the primary concern of management, rather than concentrations or loads of nutrients in and of themselves.

To this end, 21 algal bioassays were performed by culturing a green algae (Selenastrum Capricornutum) in laboratory flasks containing known concentrations of filtered urban runoff, (OWML, 1983, Chapter 12). Bioassays were conducted over a four to seven day period, after which the test cultures were measured for biomass levels. Since the growth dynamics and nutritional requirements of Selenastrum are well known, it is possible to compare the biomass levels attained in test cultures with theoretical productivity levels, (Miller, 1974) to determine the degree to which algal growth stimulation occurs. A second dimension of the nutrient bioavailability study was a comparison of algal productivity levels achieved before and after urban stormwater passed through a BMP structure. This arrangement allowed for a preliminary evaluation of the degree of algal growth limitation created nutrient removal occurring within BMPs.

### Bioavailability of Nutrients in Urban Runoff

Results of the OWML bioassays provided clear evidence that the nutrient levels typically found in urban stormwater are sufficient to stimulate the growth of high levels of algal biomass. Algal biomass produced exceeded the "high" productivity levels reported by Miller (1974) by a factor of 1.3 to 13.5 in BMP inflow test cultures. In all cases, the nutrient which limited maximum algae growth was nitrogen. This is somewhat contrary to conventional wisdom, which suggests that phosphorus is usually the limiting nutrient in freshwater systems. However, the N to P ratio, which is often used as an indicator of likely nutrient limitation, typically ranged between 9:1 and 12:1 in most Washington area urban runoff samples. N to P ratios within this range are normally considered to be on the borderline between either nitrogen or phosphorus limitation.

As noted earlier, the bioassay cultures were performed on filtered urban runoff samples. This process effectively eliminates the possibility that particulate nutrient forms may subsequently become available for algae growth. Since the particulate fraction of both nitrogen and phosphorus in urban stormwater runoff is usually greater than the soluble fraction, it appears that undiluted urban runoff has the significant potential to induce eutrophication in standing waters.

### Effect of BMPs on Nutrient Bioavailability

The overall effectiveness of BMPs in reducing overall algal growth potential appeared to closely reflect the relative nutrient removal capability of the individual BMP. For example, "wet" stormwater ponds, which were previously demonstrated to remove soluble nutrient forms quite readily (Chapter 2), were also capable of significantly reducing algal growth potential. Algae cultured in wet pond outflow produced an average of 60 percent less biomass than algae cultured in wet pond inflow. Maximum reductions of algal growth in wet pond outflows were on the order of 95 percent. By way of contrast, only a 10 percent average

reduction in biomass production was reported after stormwaters had passed through the "dry" stormwater pond.

Grassed swales and infiltration pits also did not appear to have a significant potential for curtailing algae biomass production by way of nutrient limitation. Algae cultured in the outflow from these BMPs yielded biomass levels which approached or exceeded levels reported for algae cultured in uncontrolled urban runoff. Although no on-site experimental controls existed with which to make a direct comparison, the high productivity attained in the grass swale and infiltration pit outflow is consistent with the fact that neither experimental BMP was able to remove inorganic nutrients effectively (Chapter 2). Finally, the one algal assay performed on the outflow from a porous paving site indicated that algal growth potential had been sharply curtailed. The algae cultured from the porous pavement runoff yielded the lowest biomass recorded in any of the bioassays. Phosphorus limitation was thought to be the primary influence for the moderate biomass production in the assay, and this can probably be attributed to the high levels of phosphorus removal (upwards of 60 percent) achieved in the porous pavement BMP.

Further details concerning the urban runoff nutrient availability study are presented in Chapter 12 of the VPI&SU Final NURP Report (OWML, 1983).

## SETTLING BEHAVIOR OF POLLUTANTS IN URBAN RUNOFF

The superiority of extended detention dry stormwater ponds in removing pollutants relative to conventional dry stormwater ponds was demonstrated in the BMP field studies (Chapter 2). The major reason cited for the improved performance of the extended detention dry ponds was that more time was provided for pollutant removal by gravity sedimentation and chemical flocculation. A series of laboratory settling column experiments was initiated by the OWML to shed more light on the settling dynamics of urban stormwater so as to define the maximum degree of removal that could be achieved by extended detention.

In these experiments, seven urban stormwater samples collected from commercial areas were introduced into a six foot plexiglass settling chamber. Sampling ports were located at every foot along the settling chamber, and samples were withdrawn at intervals of 2, 6, 12, 24 and 48 hours. The downward movement of pollutants was measured, and a removal rate was calculated, based on the percentage of influent concentration which migrated to a four foot depth. Some of the more interesting results of the experiments are presented below:

- There appeared to be an upper limit on the maximum amount of removal that can be achieved by settling alone (Figure 5.6). For sediment, this upper removal threshold was approximately 90 percent. By way of contrast, the maximum removal rate for total nitrogen and phosphorus after 48 hours was only 40 percent. Even a smaller rate was observed for nitrate (10 percent). For COD, the maximum removal after 48 hours approached 50 percent. One conclusion which might be drawn is that if control of nutrient enrichment or oxygen demanding materials is a primary management objective, then stormwater design features other than extended detention will be required to remove pollutants.

Figure 5.6  
 POLLUTANT REMOVAL ACHIEVED AFTER 6 AND 48 HOURS OF EXTENDED  
 DETENTION: EXPERIMENTAL SETTLING COLUMN STUDIES

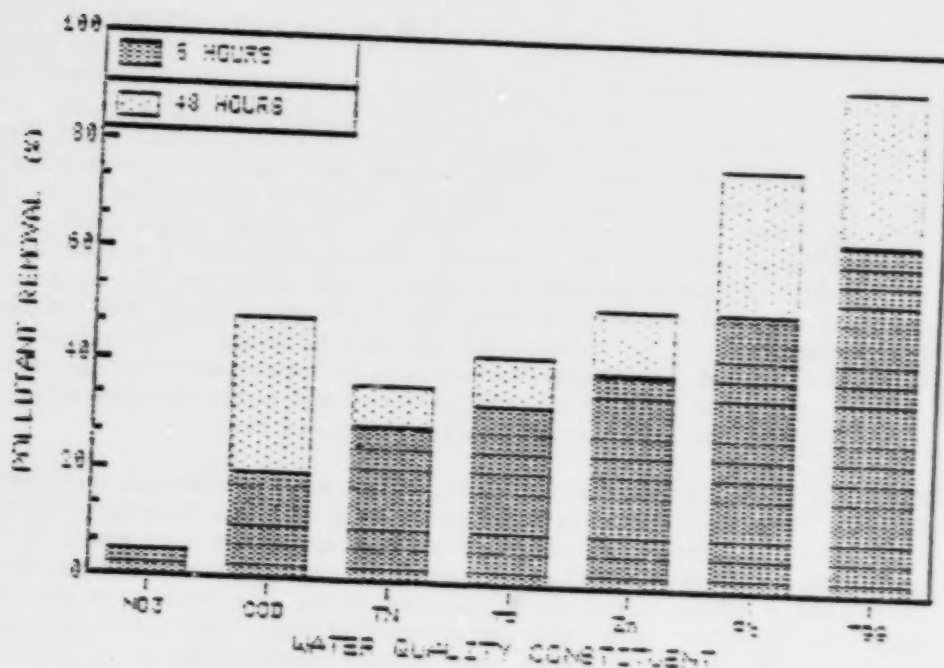
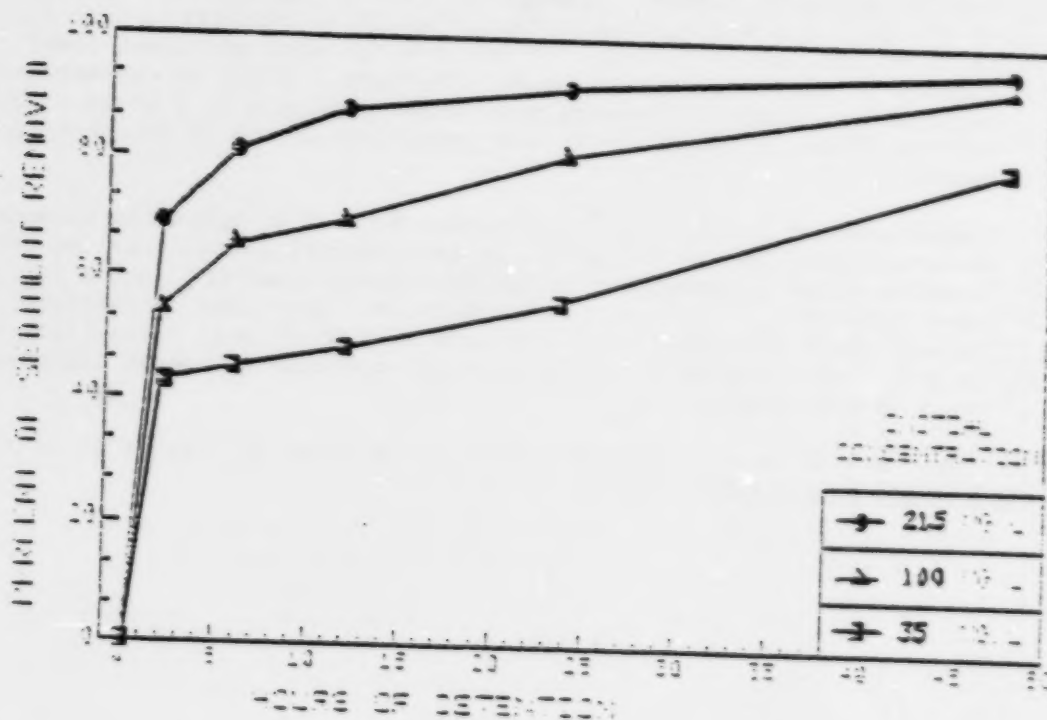


Figure 5.7  
 SEDIMENT SETTLING RATES OBSERVED AT DIFFERING  
 INFLUENT CONCENTRATIONS





- The settling rate for most pollutants was extremely sensitive to the initial pollutant concentrations, such that the highest settling rates were almost always associated with the stormwater samples which had the greatest initial concentration (Figure 5.7). Also, most of the pollutants in the stormwater runoff samples behaved like a mixture of discrete and flocculant solids, with discrete solids rapidly settling out (within a few hours) while the flocculant solids gradually settled over a period of several days. The practical implication of this phenomenon is that the removal rate for most pollutants was logarithmic in nature. This is best exemplified in Figure 5.6 which shows that at least two-thirds of the maximum potential removal for nearly all water quality parameters occurs within six hours. For example, 65 percent of the sediment removal occurred within the first six hours, whereas the next 15 percent removal increment took another 42 hours. Therefore, the design of extended detention ponds could be conceivably oriented toward achieving a 6 to 12 hour detention time, and still achieve significant percentage of the long-term pollutant removal rate.
- Analysis of the particle size distribution of suspended sediments indicated that over 80 percent of the particles were less than 35 microns in diameter. These fine sediment particles have a much greater surface area than do larger particles, per unit mass. As a consequence of the increased surface area, more binding sites are available for attachment of organic and inorganic pollutants. Statistical analysis conducted by OWML indicated that a very high correlation existed between incremental reductions in particle surface area and incremental reductions of total phosphorus, organic nitrogen and several trace metals. Further statistical analysis was performed to identify the precise particle size fraction which was most responsible for observed reductions in pollutant concentrations. For most pollutants studies, the removal of 25 to 45 micron sized particles produced the greatest overall pollutant removal. Therefore, from an engineering standpoint, it was felt that the stormwater design should be oriented to trap sediments within this size range to achieve the most efficient level of removal of particulate associated pollutants. Based on conventional engineering theory, it appears that approximately 6 to 8 hours of detention would be required to trap particles in the 25 to 45 micron range.
- Comparisons of actual field monitoring data of an operating extended detention pond (Stedwick) with the experimental settling column data revealed close agreement as to the approximate removal of urban pollutants after a six hour period of detention. The close correspondence between field and laboratory data sets lent additional credibility as to the overall validity of the general conclusions reached independently in both studies.

More details on this special study can be found in Chapter 11 of the VPI&SU Final Report (OWML, 1983).

## SUMMARY OF SPECIAL URBAN RUNOFF STUDIES

**Priority Pollutant Scan.** Only 28 out of 128 toxic chemicals were discovered in 15 stormwater runoff samples analyzed in the Washington area. In general, the detected toxicants were present in quantities which posed little or no environmental risk. The most frequently detected toxic pollutants were inorganic trace metals such as cadmium, copper, lead, nickel, selenium and zinc. Although many of these metals occasionally violated U.S.EPA criteria for protection of aquatic life, human health or drinking water, the actual significance of the violations is not well understood at the present time. Extremely low levels of several pesticides (less than 0.1 parts per billion) were detected in some samples. While suggesting an apparent link between residential insecticide application and contamination of urban runoff, the detected levels of pesticides apparently pose no serious risks to either human health or aquatic life. In addition to the trace metals and pesticides, six organic compounds were found in one or more of the samples. Without exception, none of the organic compounds were detected at levels considered toxic to either human or aquatic life.

**Downtown Central Business District Loading Study.** A comparison of average concentrations of pollutants in urban runoff generated from suburban and downtown central business districts suggested that loadings from both areas were similar in magnitude, and both were substantially higher than any other residential or commercial land use monitored in the NURP or 208 studies. However, due to monitoring problems, there was insufficient data to statistically validate either inference.

**Trace Metal Accumulation and Movement Monitoring.** Substantial accumulations of cadmium, copper, lead and zinc had occurred within the sediments of stormwater basins. This finding provided additional evidence that trace metals are effectively removed in ponds which detain stormwaters for extended periods (whether by accident or design). Surface soils in the stormwater basins studied had a trace metal content which was generally lower than that of regionally produced sludge. Since composted sludge is frequently applied to the land throughout the region, it appears that disposal of dredged stormwater sediments should not present serious problems. Although surface soil metal levels were substantial, concentrations declined rapidly with depth. This finding suggested that the risk of accumulated trace metals contaminating ground water supplies by downward leaching is probably not significant.

Grassed swales soils did not exhibit any net accumulation of lead or copper. Observed accumulation of cadmium and zinc in the swales appeared to have been caused by release of trace metal from galvanized culverts during runoff, rather than any pollutant removal process operating within the swale. Taken together, the soil metal data collected in the grass swales confirms the field monitoring data (Chapter 2) which suggests that swales have extremely limited value in terms of pollutant removal under current design standards. Soil trace metals did not appear to be leaching downward through the soil profile.

**Bioavailability of Nutrients.** Bioassays provided clear evidence that the dissolved nutrient burden in undiluted urban stormwaters was more than sufficient to highly stimulate the growth of algae in test cultures. Wet ponds and porous pavements were found to be very effective in reducing the

algal growth potential. In several instances, reductions of up to 95 percent of the potential algal biomass were achieved. By contrast, dry ponds, grassed swales and infiltration devices proved to be relatively ineffective in reducing the algal growth potential by way of nutrient limitation. In general, the results of the algal assays on BMP inflows and outflows closely reflects the capability of the BMP to remove inorganic nutrients.

**Settling Dynamics of Urban Runoff.** Settling column experiments revealed that the majority of pollutant removal which can be achieved by physical settling will occur in the first 6 to 12 hours of detention. Thereafter, incremental pollutant removal is very gradual. Also, the experiments suggested maximum upper limites on the amount of pollutant removal possible by settling alone. For sediment, this threshold was 90 percent, while for total phosphorus, total nitrogen and chemical oxygen demand, maximum removal rates seldom exceeded 50 percent. Highly soluble chemicals such as nitrate-nitrogen usually stay entrained in the water column; less than 10 percent settled out over a 48-hour period. The clear implication is that if control of nutrients or oxygen-demanding materials is an important management priority, then extended detention alone will not achieve maximum results.

## REFERENCES

- Chaney, 1980. "Sludge Management: Risk Assessment for Plant and Animal Life" in Proceedings of 1980 Spring Seminar Sludge Management in the Washington, D.C. Metropolitan Area. National Capital Section, ASCE, pp. 8-16.
- Dalton, Dalton and Newport, 1982. "Draft Report, NURP Priority Pollutant Monitoring Program, Volume I: Findings." Prepared for USEPA, 65 pp.
- EPA, 1983. Final Report to Congress, Nationwide Urban Runoff Program.
- Helsel, D., Kim, J., Grizzard, T., Randall, C., and R. Hoehn, 1979. "Land Use Influence on Metals in Storm Drainage." Journal Water Pollution Control Federation 51:709-717.
- JTC Environmental Consultants, 1982. "Final Report: Priority Pollutant Analysis," prepared for Metropolitan Washington Council of Governments.
- Metropolitan Washington Council of Governments, 1981 (MWCOC). Interim Report: Washington Area NURP Project, Vol. II, Appendix III, "Downtown Central Business District Loading Study," 36 pp.
- Miller, W., T. Maloney, and J. Greene, 1974. Water Research 8:667-679.
- Northern Virginia Planning District Commission (NVPDC) 1979. Guidebook for Screening Urban Best Management Strategies. Report prepared for Metropolitan Washington Council of Governments. 160 pp.
- O'Brien and Gere, 1983. Final Report, Combined Sewer Overflow Program, prepared for D.C. Department of Environmental Services.



**CHAPTER SIX**  
**PROTOTYPE WATERSHED**  
**NONPOINT SOURCE**  
**MANAGEMENT STUDIES**

## CHAPTER VI

### PROTOTYPE WATERSHED NONPOINT SOURCE MANAGEMENT STUDIES

#### INTRODUCTION

The final element of the metropolitan Washington NURP project was a comprehensive analysis of nonpoint source management needs and control options in two local urbanizing watersheds (Seneca Creek and Piscataway Creek). The analysis focused on development and application of sophisticated watershed modeling tools designed to assist local land use planners in identifying cost-effective management strategies for controlling urban and agricultural runoff.

The Seneca and Piscataway watershed management studies were oriented to evaluate the impacts of urbanization on water quality and stream habitat in a manner which could be directly incorporated into the land use planning and regulatory efforts of area local governments. Both studies made full use of recent research on the cost and pollutant removal capability of urban BMP's and land use/nonpoint loading relationships developed in regional 208 and NURP planning studies. Both studies also had considerably broader focus than the EPA NURP program in that they emphasized not only the water quality impacts associated with urban runoff, but also addressed the physical impacts of stormwater runoff on stream habitat as well. Additionally, the studies examined the relative influence of agricultural and urban nonpoint loadings, which are often characteristic of transitional watersheds.

Efforts were made to compare the relative effects of different land use options and levels of urban and agricultural runoff control on overall water quality and stream conditions. Cost estimates for urban and agricultural runoff controls were also developed to illustrate the relative cost-effectiveness of different land use/control combinations. From this work a series of specific runoff management recommendations were made for each watershed.

#### Organization Of Chapter

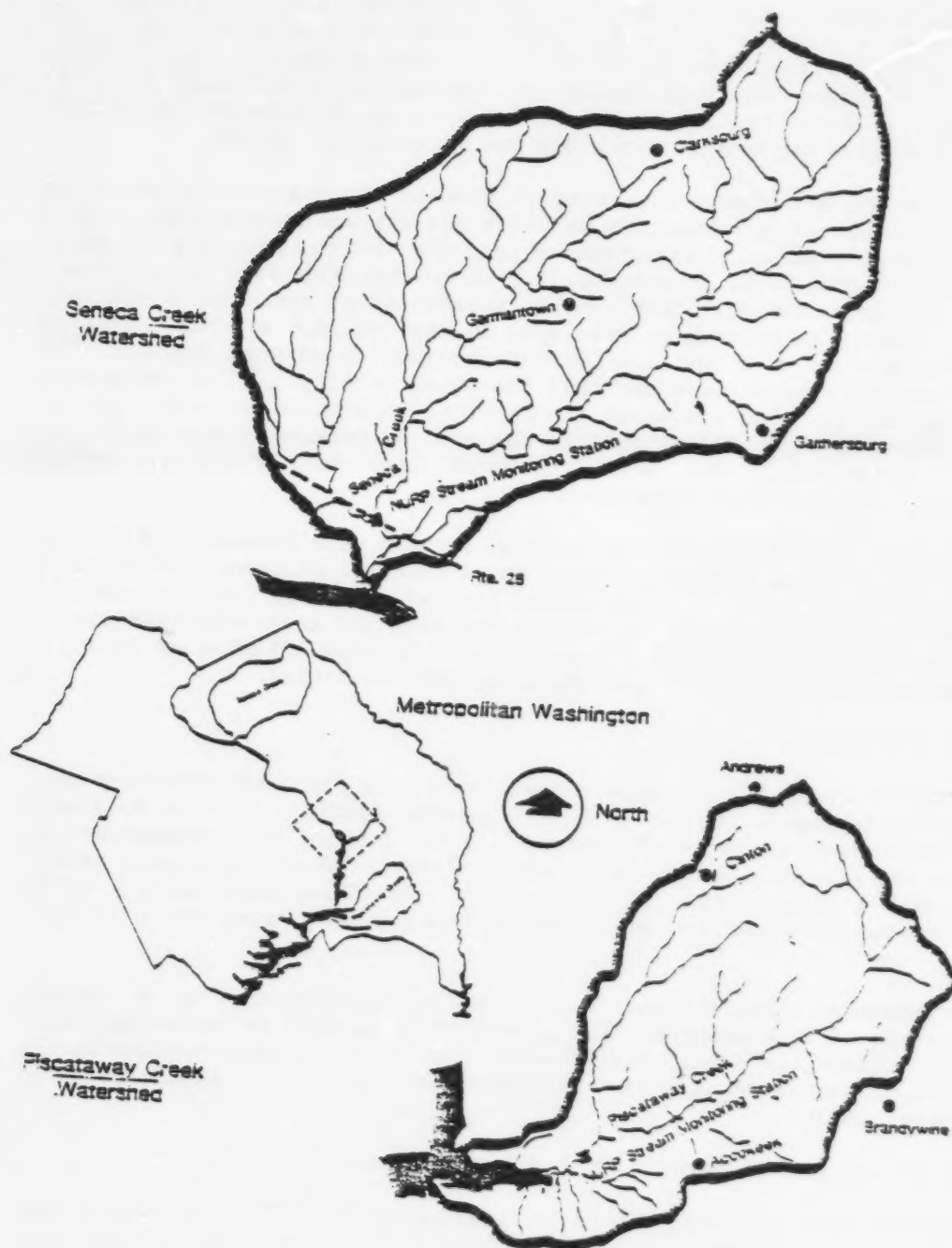
This chapter begins with a general outline of the five step prototype watershed planning approach utilized in both watershed studies, followed by a more specific presentation of the more interesting conclusions and recommendations derived from the process. Reference is made to resources and techniques necessary to conduct a large scale watershed study. Potential implications which these studies may have for regional nonpoint source management are also discussed.

A comprehensive description of each watershed management study is clearly beyond the scope of this chapter. The reader is encouraged to review the final reports which thoroughly detail the methods, results and recommendations on the Seneca and Piscataway Creek watershed management studies (MWCOC, August 1983 and MWCOC, November 1983).

#### Selection of Seneca and Piscataway for Prototype Studies

In December 1980 the Water Resources Planning Board (WRPB) completed a comprehensive ranking of watersheds in the Washington region in terms of their non-

Figure 6.1  
LOCATIONS OF SENECA AND PISCATAWAY CREEK WATERSHEDS



point loading contributions to critical receiving waters. Relative nonpoint source management priorities were evaluated in the region by comparing existing and forecasted total and unit acre nutrient and oxygen demanding loads for each of the 42 watersheds. Using a set of uniform criteria, watersheds were identified which were "critical" because of their relative nonpoint load contributions and potential for adverse impact to key receiving waters (MWCOG, Dec., 1980). Based upon this ranking process and subsequent consultations with local officials and planners, the Seneca Creek Watershed in Northwestern Montgomery County, and the Piscataway Creek Watershed, situated in southwestern Prince George's County, were selected for the performance of prototype nonpoint source management investigations. The locations of these watersheds within the region can be seen in Figure 6.1.

## PROTOTYPE WATERSHED PLANNING APPROACH

A prototype approach was designed and applied to analyze watershed runoff management issues within a hierarchical framework. Five distinct steps were applied in the Seneca and Piscataway studies. These steps are summarized on Figure 6.2. Major steps were water quality monitoring, watershed model development, model application, economic analysis, and study integration. Principal features of each step are outlined below.

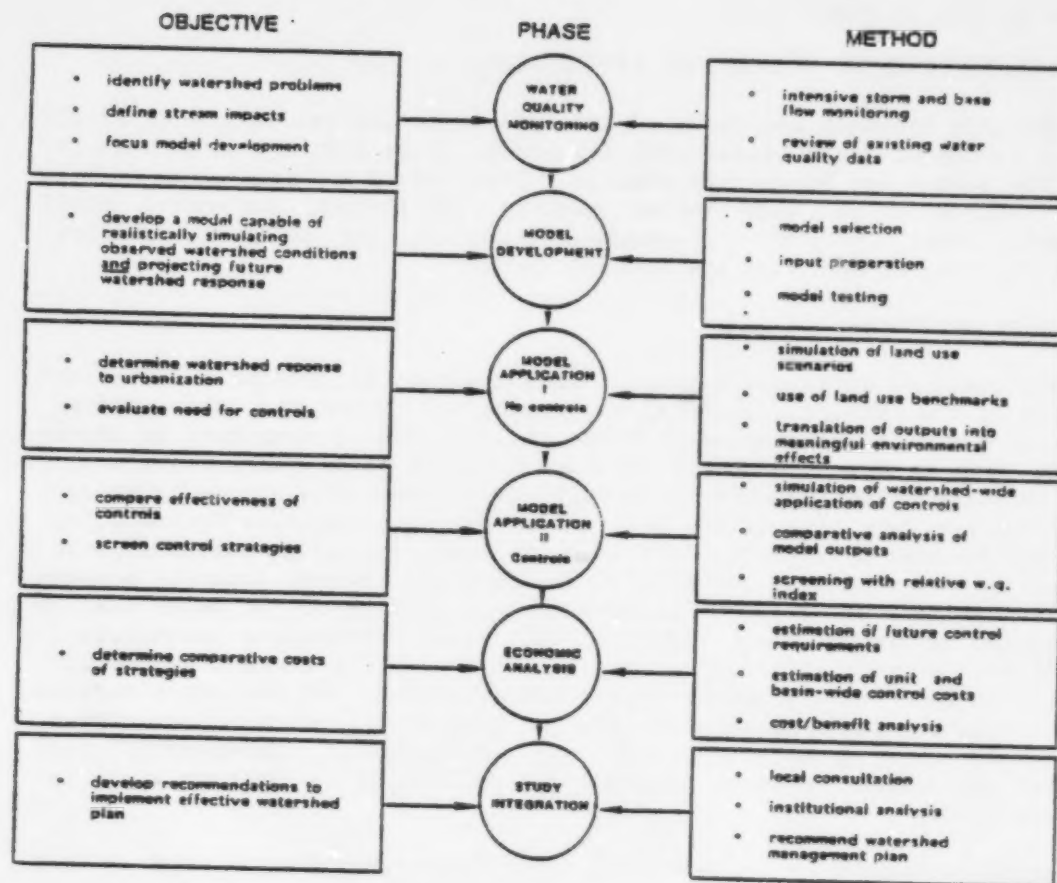
### Water Quality Monitoring

A well designed water quality monitoring program can furnish a better understanding of the physical, chemical and biological nature of a stream system. The collection and interpretation of water quality data is therefore an important first step in the development of a technically sound and scientifically credible watershed planning effort. As such, development of a strong hydrologic and water quality data base is not only a necessary prerequisite for modeling, but also can be used to identify watershed problems, and define stream impacts. This knowledge, in turn, can serve to focus the study towards concrete management objectives from the outset. As an example, analysis of the water quality data collected in Seneca Creek indicated that some constituents (particularly pollutants such as nutrients and sediment) were present in concentrations that posed potentially serious problems within the watershed, and therefore merited special attention. Other parameters, such as temperature and dissolved oxygen, did not appear to be greatly affected by pollutant loads. Consequently, much less effort was concentrated on studying the pollutants influencing these in-stream parameters.

A second consideration in designing a watershed monitoring program is that it provide the most complete and comprehensive picture of stream conditions as possible. A monitoring program involving grab samples of a handful of water quality parameters over a few months may be useful in assessing long term trends, but is not sufficient basis for development of watershed models or identification of watershed impacts. Therefore, the monitoring program undertaken in the Seneca and Piscataway studies emphasized the collection of a wide variety of water quality parameters (nearly 50 in all) using automated samplers over an extended period of time (approximately 18 months). The instrumentation of the monitors was designed to directly couple flow and water quality measurements in the field to obtain flow weighted composite samples. These sampling procedures allowed for accurate measurement of pollutant concentrations during both storm-flow and baseflow periods. Automated flow-compositing sampling techniques had the additional benefit of providing estimates of mass loadings of nonpoint pol-



Figure 6.2  
A PROTOTYPE APPROACH FOR WATERSHED PLANNING



lutants. (A complete description of the monitoring set-up is provided in C&ML (1983).

Another feature of the water quality monitoring phase involved the careful review of all known historical water quality data-sets collected in each watershed. By combining all of the available water quality data, long term trends in water quality parameters could be assessed and rates and constants could be determined for modeling purposes. A detailed presentation of the major aspects of the monitoring phase of the watersheds studies can be found in MWCOG (September 1982) and MWCOG (July 1982).

## Model Development Phase

### Model Selection

The first step in the development of a watershed model is the selection of an appropriate computer model. Many computer models exist which are applied to watershed planning, and most differ widely in their scope, flexibility, complexity and capability. Two of the fundamental criteria underlying the selection of a model for this study were that the model 1) be fully capable of simulating a wide variety of watershed and in-stream processes and 2) be flexible enough to accommodate a wide variety of management alternatives in the application phase. The model selected as most closely fulfilling both criteria was the Hydrological Simulation Program-Fortran (HSPF) model, developed over a number of years by the Environmental Protection Agency.

HSPF is a continuous simulation model that integrates numerous watershed hydrology, receiving water quality, sediment transport and nonpoint sources pollution algorithms into a single comprehensive model. Table 6.1 highlights some of the more important watershed and stream processes simulated in the HSPF applications, as well as some of major model outputs. A complete description of the structure and capabilities of the HSPF model as it was applied in the Seneca and Piscataway Creek watersheds can be found in MWCOG, (May 1983) and MWCOG (August 1983) (A generic documentation report of the basic HSPF model framework is supplied by Anderson Nichols (1982) and Hydrocomp (1981).)

### Model Preparation

The second element of model development involves the preparation of model inputs and the estimation of model parameters. Compared to most existing water quality models, HSPF is relatively complex and has large input data requirements. Over two hundred different parameters are necessary to operate the model, many of which vary by land use, channel location or by season. Model operation also requires the preparation of extensive inputs which describe climatic, water temperature, point source loadings, land use conditions, and channel characteristics.

As a result of HSPF's inherent complexity, considerable resources were devoted to adequately characterize both inputs and parameters. Watershed and stream data were collected from a variety of local agencies such as M-NCCPC, USGS, WSSC, NWS, etc. Geomorphological studies of Seneca Creek conducted over the past thirty years were also extremely valuable in characterizing sediment transport. Local modeling studies conducted by NVPDC in the Occoquan Basin, which used a precursor model to HSPF, also proved to be extremely helpful in es-

Table 6.1  
MAJOR PROCESS SIMULATED AND KEY OUTPUTS DERIVED FROM  
THE HSPF MODEL

PERVIOUS LANDS

- Surface and subsurface runoff
- Soil erosion
- Generation/transport of NPS pollutants

IMPERVIOUS LANDS

- Surface runoff and solids washoff
- Accumulation/washoff of NPS pollutants

CHANNEL REACHES

- Stream hydrology/hydraulics
- Transport of water quality constituents
- Point source loadings
- Streambank erosion/sediment deposition
- Dissolved oxygen budget and nutrient transformations

HSPF Outputs

- |                                    |                           |
|------------------------------------|---------------------------|
| • Hourly discharge                 | • Dissolved oxygen levels |
| • Sediment concentration frequency | • Nitrate                 |
| • Streambank erosion               | • Ammonia                 |
| • Channel deposition               | • Organic-N               |
| • BOD load                         | • Total phosphorus        |

timating parameters. HSPF applications elsewhere in the country, and other literature sources were also consulted, if no primary data source was available. In these cases, sensitivity analyses were often conducted to assess the overall importance of the parameter within the context of the entire model.

#### Model Testing

The next step in the model development phase involves model calibration. This is an iterative procedure of model parameter evaluation and refinement whereby the model simulated outputs are directly compared with observed data. This procedure is used to increase the realism, generality and accuracy of the model.

To insure that the model is fully capable of simulating watershed processes over a wide range of seasonal and climatic conditions, it is necessary to conduct the calibration over a significant period of time, and over several hierarchical levels of spatial and temporal resolution. For example, in both Seneca and Piscataway Creek, the hydrology calibration was conducted over a four year period (1967-1970). Within this period, observed/simulated comparisons were made at annual, monthly, and daily, and individual storm levels. Flow duration analysis was also performed. Once a reasonable level of agreement between observed and simulated discharge was achieved, the model was then verified over an additional five year period. (1970-1975) This verification procedure essentially involves running the model without changing the calibration parameter set and examining observed and simulated outputs. If a good correspondence between the simulated and observed runoff values obtained, then the model is considered to be successfully developed.

After the calibration/verification of the hydrology component of the HSPF model, the next step involves the calibration of water quality parameters such as sediment, nutrients and oxygen-demanding materials. The same general calibration protocol utilized for hydrology was followed. Both mass loading and concentration values were compared to model outputs on an annual and individual storm basis, over the full 18 month monitoring interval. Due to lack of a good data-base beyond this interval, no model verification tests were conducted.

The final step of this phase involved the thorough documentation of all aspects of model development. Unfortunately, the documentation step is often a neglected aspect of model development, but is very important for a number of reasons. First, it allows for the independent review of the relative strengths and weaknesses of the model. This evaluation is necessary since the overall adequacy of the calibration/verification efforts directly conditions the usefulness and reliability of models in subsequent management-oriented applications. Secondly, lack of appropriate documentation makes it difficult for future model users to run the model. Model documentation in this study included a presentation of the complete input stream, along with supporting information on how key parameters and inputs were prepared. Also, the major assumptions and limitations underlying the model were outlined and the graphical and statistical results of model testing were described. (MWCOC, November 1983; Tech. Papers C and D; MWCOC, August 1983; MWCOC, May 1982)

These references provide graphical and statistical summaries of comparisons and observed and simulated outputs. A few representative plots are depicted on the following pages (Figures 6.3 through 6.6). However, anyone who wishes to fully understand the modeling aspects of these critical watershed studies is urged to examine each of these references closely.



Figure 6.3  
COMPARISON OF OBSERVED AND SIMULATED ANNUAL RUNOFF VOLUMES  
RECORDED AT DAWSONVILLE, MD (SENECA CREEK) 1967-1975

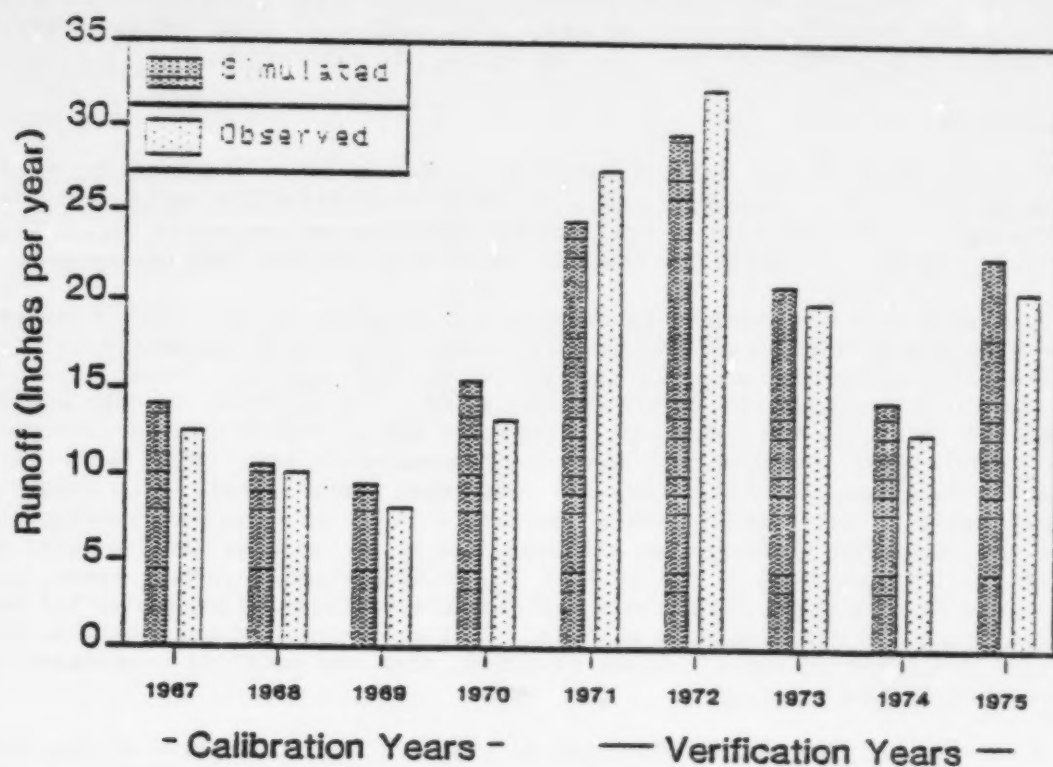


Figure 6.4  
OBSERVED AND SIMULATED STORM SEDIMENT YIELDS AT  
DAWSONVILLE, MD (SENECA CREEK) 1980-1981

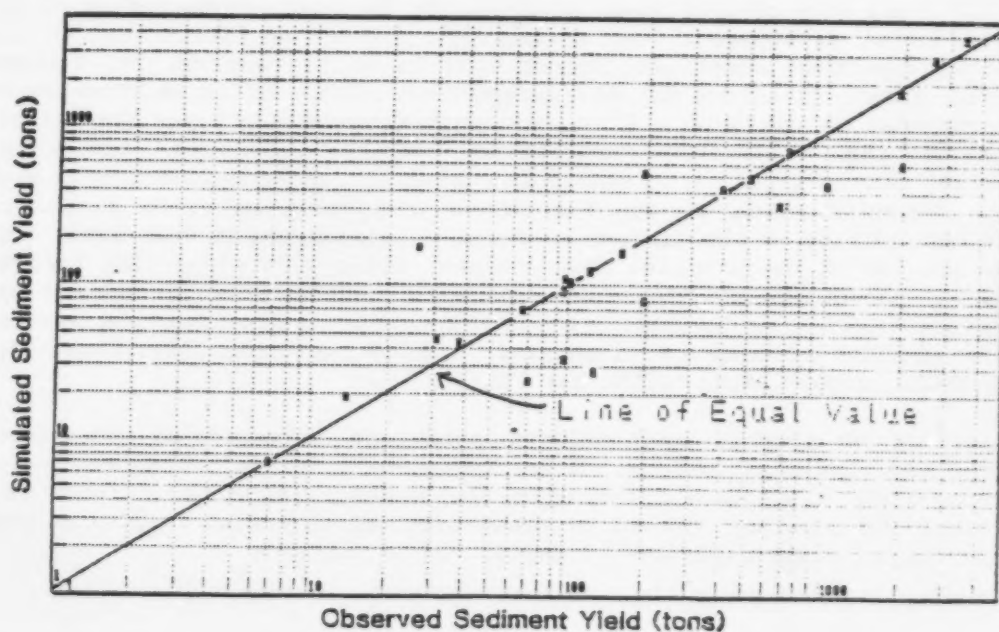


Figure 6.5  
OBSERVED AND SIMULATED STORM TOTAL PHOSPHORUS LOADINGS  
AT PISCATAWAY CREEK NURP MONITOR: 1980-1981

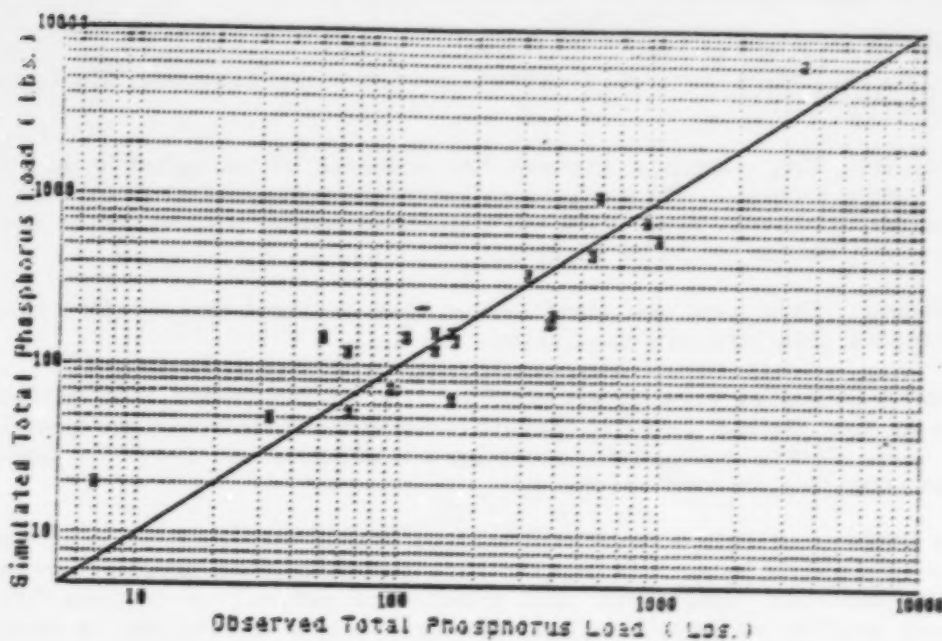
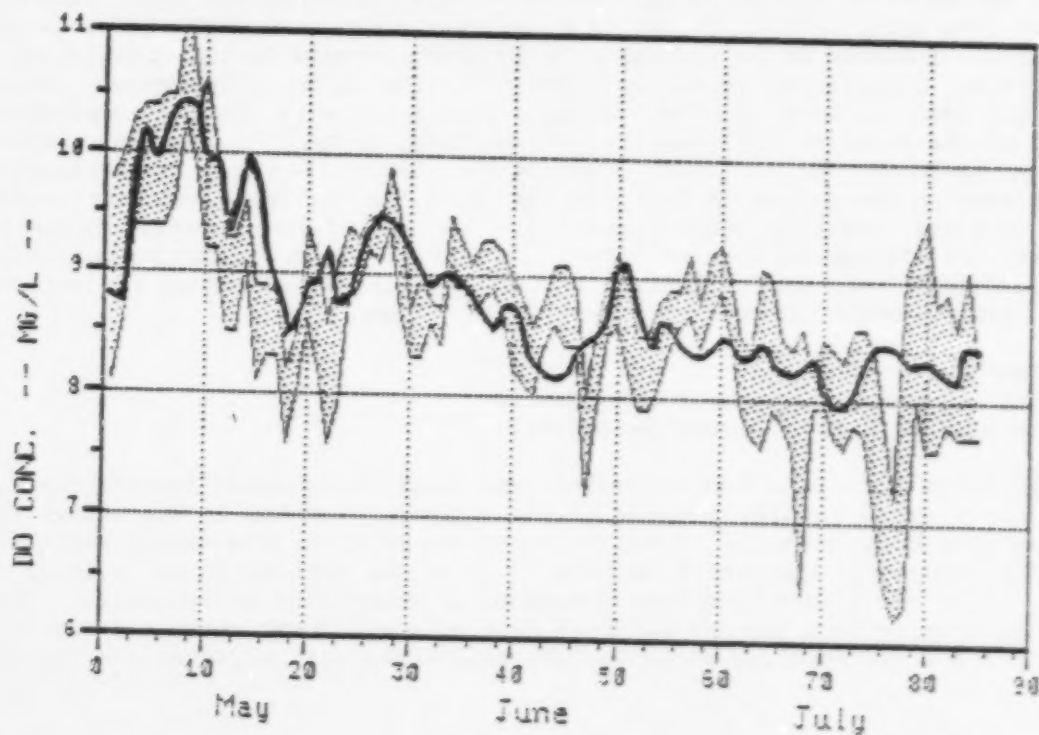


Figure 6.6  
CONTINUOUS SIMULATION OF INSTREAM DISSOLVED OXYGEN LEVELS  
RIFFLEFORD ROAD, MD (SENECA CREEK) SUMMER, 1974



## Model Application Phase I (Alternative Land Use Scenarios: No Controls)

After the watershed models had been successfully calibrated, they were applied to project the watershed response to several alternative land use scenarios; including,

**Pristine:** This scenario assumed the presence of an undeveloped watershed with full forest cover. This condition was used to represent a baseline, or natural background level, from which the watershed response to existing and future levels of development could be assessed.

**Existing:** This land use scenario was also utilized to provide a benchmark, and represents 1980 land use conditions.

Future scenarios were provided by local planning staffs, and included some estimate of the maximum level of development anticipated over the next 15 to 20 years. Also, future scenarios involving an intermediate level of development were also simulated in many cases.

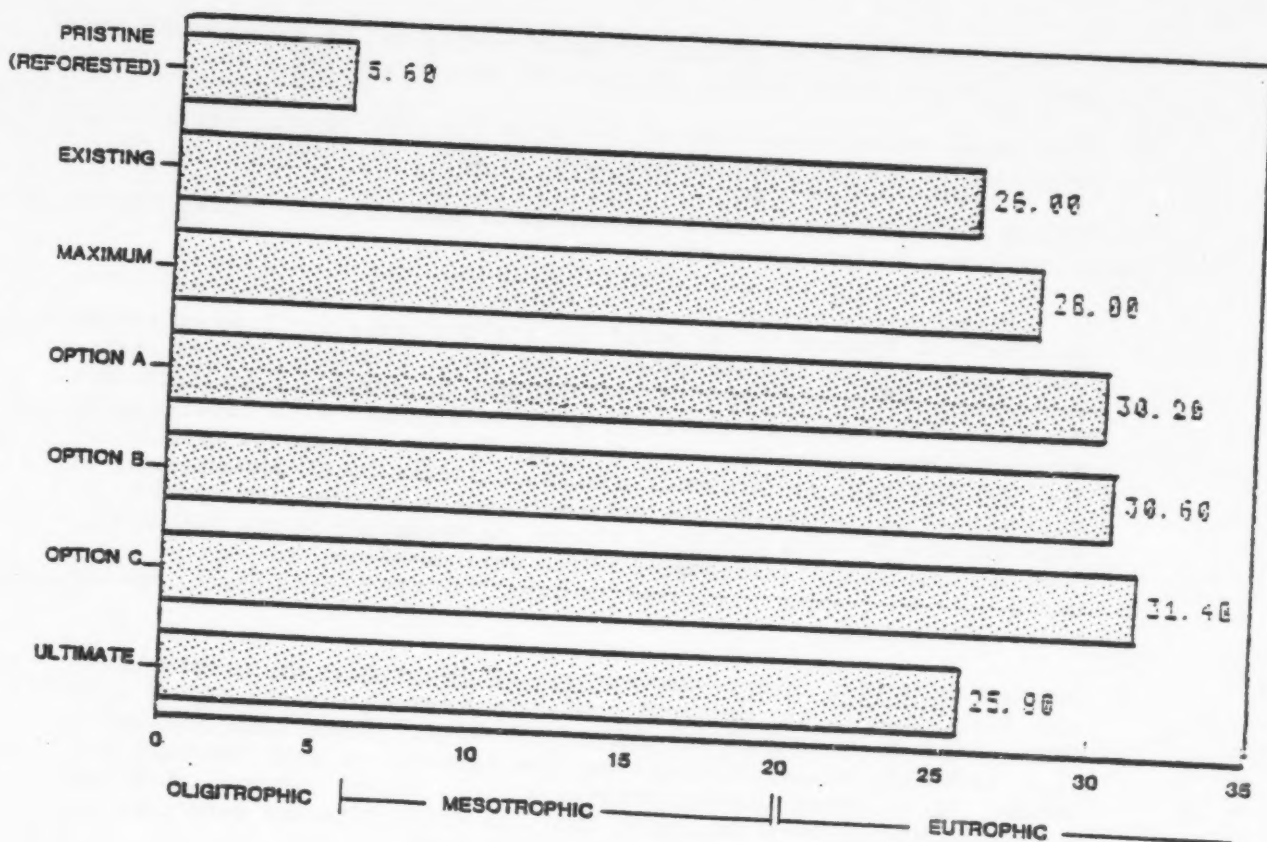
The utility of this approach is that it allows for comparisons of how simulated water quality under a future land use scenario would relate to water quality under existing conditions and under more natural or optimum "pristine" conditions unaffected by man. Thus, the existing condition can be compared to the pristine condition, or each future scenario can be examined in relation to existing conditions. As a result, the projections can be viewed in terms of the degree of change in water quality conditions one might expect relative to an initial benchmark. Another advantage of this approach is that it can be used to identify optimum target levels of water quality.

A common criticism of some watershed modeling studies is that they only provide estimates of the annual mass of pollutants delivered to a downstream water body (for example, 350,000 lbs of X per year). Thus, decision-maker is offered little guidance as to whether a 15 percent increase in the quantity of X will have any significant impact on beneficial uses of receiving waters. Under the Seneca and Piscataway studies, attempts were made to express the comparative outputs of the model in environmentally meaningful terms. For example, projections of nutrient and sediment loadings were translated into more tangible impacts such as the number of days per year with high sediment concentrations; estimated algal levels in basin impoundments; percent of lake capacity filled by sediment, and streambank erosion rates. An example of such comparisons is provided in Figure 6.7, and the entire set of such comparative model projections can be found in MWCOG (November 1983) and MWCOG (August 1983).

## Model Application Phase II (Alternative Land Use Scenarios Simulated in Combination with Runoff Control Scenarios)

The first stage of the model application phase was oriented towards identifying future water quality impacts within a given watershed in the rather restricted case of no controls. Application of the model in this manner permitted the water quality and quantity impacts of land use options to be isolated so that the need for a watershed runoff control program could be evaluated. This stage has usually been the end point of most previous local watershed modeling efforts; i.e., uncontrolled water quality conditions are projected for the fu-

Figure 6.7  
 PROJECTED MEAN ANNUAL CHLOROPHYLL "a" LEVELS IN LITTLE  
 SENECA LAKE UNDER FUTURE LAND USE SCENARIOS AND  
 DIFFERING CONTROL PROGRAMS





ture, and if they appear sufficiently undesirable from a management standpoint, then broad recommendations for implementation of a BMP control program are usually made.

However, since the relative effectiveness, applicability, and cost often varies considerably between generic control programs, several additional questions were addressed in the context of the Seneca and Piscataway studies.

1. Of all of the generic control programs available, which ones are the most effective in mitigating instream and downstream impacts?
2. What level of implementation of the effective control programs will be necessary to achieve a reasonable level of water quality protection?

The Seneca and Piscataway studies attempted to address these rather difficult questions in the following manner:

- An essential feature of the model application phase involved extremely close coordination between modelers and local planners and engineers. The chief objective of such interaction was to identify a realistic set of control strategies that: 1) were consistent with local design standards and engineering technologies; 2) were reasonable in light of the institutional and economic realities facing local governments; 3) reflected both realistic and optional levels of compliance; and, 4) were capable of being simulated within the framework of the HSPF model. Some of the control strategies which were developed in this process, and were subsequently simulated in detail in the Seneca study, are depicted in Table 6.2.
- Another important feature was the direct integration of the results of the field studies on comparative pollutant removal capability of urban BMPs (Chapter 2) within the model framework. These data provided a firm technical basis for comparing the response of each critical watershed to selected control strategies. Pollutant removal rates for each generic BMP were estimated from the field data and were then directly integrated in the model production runs.
- Considerable emphasis was also placed on the methods used to incorporate the selected control programs into the framework of the model. In the case of "wet" and "dry" type stormwater management ponds, for example, runoff and pollutants generated from new development were routed through simulated storage basins before entering the stream channels. Storage volumes, release rates and removal efficiencies were carefully tailored to reflect current practices and basin stormwater management requirements. (More details on how this analysis was performed can be found in Chapter 6 in MWCOC (November 1983).
- A series of twenty-five model runs which simulated the watershed response to the selected control strategies (in combination with land use planning options) were executed, and outputs were compared on a graphical and tabular basis. Because of the large number and extreme complexity of the model outputs it was necessary to find some means of condensing them into a more meaningful format for decision-makers and

Table 6.2  
CONTROL STRATEGIES EXAMINED BY THE SENECA MODEL IN THE  
CLARKSBURG PLANNING AREA

### Stormwater Management Scenario

- "Dry pond" detention basins
- Apply to 70% of new development
- Flow attenuation/peak shaving of two year storm
- Minimal removal of sediment and nonpoint source pollutants
- "Hardwired" into model
- Low and high density ponds

### Urban BMP Scenario

- Use of wet ponds
- Provide stormwater plus nonpoint source control
- NPS removal rates based on NURP findings
- Applicable to 100% of all new development

### Agricultural BMP Scenario

- Based on Little Seneca 566 Watershed Conservation Plan (SCS)
- Involves cropland and animal waste management on 3100 acres, 8 dairy operations
  - Conservation tillage
  - Cover crops and crop residue retention
  - Contour & strip farming
  - Diversions and grassed waterways
  - Animal waste collection systems
- Assumes load reduction projected by SCS

### Mixed BMP Scenario

- Combination of application of agricultural and urban best management practices (wet ponds)
- Represents the maximum level of stormwater and nonpoint source control

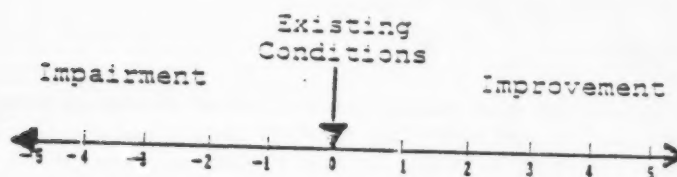
planners. To this end, a simple index was developed to provide an overall evaluation of the relative water quality levels achieved under each strategy. The index was used to present comparisons on water quality impacts from different land use/BMP strategies based on the percent change, relative to existing conditions, that would occur for each of ten important water quality indicators. The index was extremely useful in depicting, in a clear and concise manner, whether or not implementation of a control strategy would result in the deterioration, maintenance or improvement to current water quality conditions. As such the index served as a broad screening tool to identify the most and least effective mitigation strategies. A description of the index application is provided in Figure 6.8.

### Economic Analysis Phase

The cost of implementing and operating a runoff control is usually a very major consideration to be weighed in the development of an effective nonpoint source control strategy. Such information, especially when coupled with estimates of relative water quality impacts, can help planners to gauge how much "bang" for a "buck" can be expected from a particular strategy. Therefore, emphasis was placed on calculating the total cost of each control strategy, based on cost relationships developed in earlier NURP studies (Chapter 3). Some of the features of this phase of the watershed analysis are outlined below:

- Total control costs were defined in the watersheds studies as being the sum of both the initial capital construction cost of the control (including planning, design, administration and debt service) and the subsequent costs incurred in operating and maintaining the device over its useful life. This was done to insure that the entire final cost of control strategies could be compared on a similar basis.
- In the case of stormwater controls, efforts were made to quantify the stormwater storages necessary to accommodate future runoff levels associated with each land use plan in each watershed. The number and size of stormwater ponds could then be readily determined from these detailed basin-wide storage estimates. Cost estimates were then calculated for typical "unit" stormwater ponds, and the product of the cost per unit pond and the number of ponds required yielded the total basin control cost.
- Annual and cumulative total costs for each runoff control strategy were determined on both a basin-wide and unit cost basis, (such as annual cost per dwelling unit per year). This cost breakdown provides pertinent economic information for parties interested in evaluating both social and private costs.
- Basin-wide total costs were paired with relative water quality index scores for each control scenario to obtain a cost benefit curve such as shown in Figure 6.9. This allowed for a comparison of different control scenarios as a function of cost and relative water quality levels achieved. When economic data is presented in this manner, it enables decision-makers to quickly screen potential control programs on the basis of both physical and economic efficiency.

Figure 6.8  
RELATIVE WATER QUALITY INDEX USED TO SCREEN  
LAND USE AND RUNOFF CONTROL OPTIONS



- Used to condense model outputs for each land use planning/control strategy
- Provides a broad screening comparison of alternatives
- Based on percent change from existing conditions (+ or -) for ten water quality parameters
- Scale of index ranges from plus 5 to minus 5
- Each unit on scale represents a 25% increment of change, relative to existing conditions

#### Parameters Evaluated By Index

##### Impacts To Tributaries:

- Peak discharge
- Summer dry weather flow
- Streambank erosion
- Channel deposition
- Suspended sediment exceedance frequency (days > 100 mg/l)

##### Impacts To Lake:

- Total nitrogen load
- Total phosphorus load
- Total BOD-5 load
- Estimated chlorophyll "a"
- Volume of sediment delivered to lake



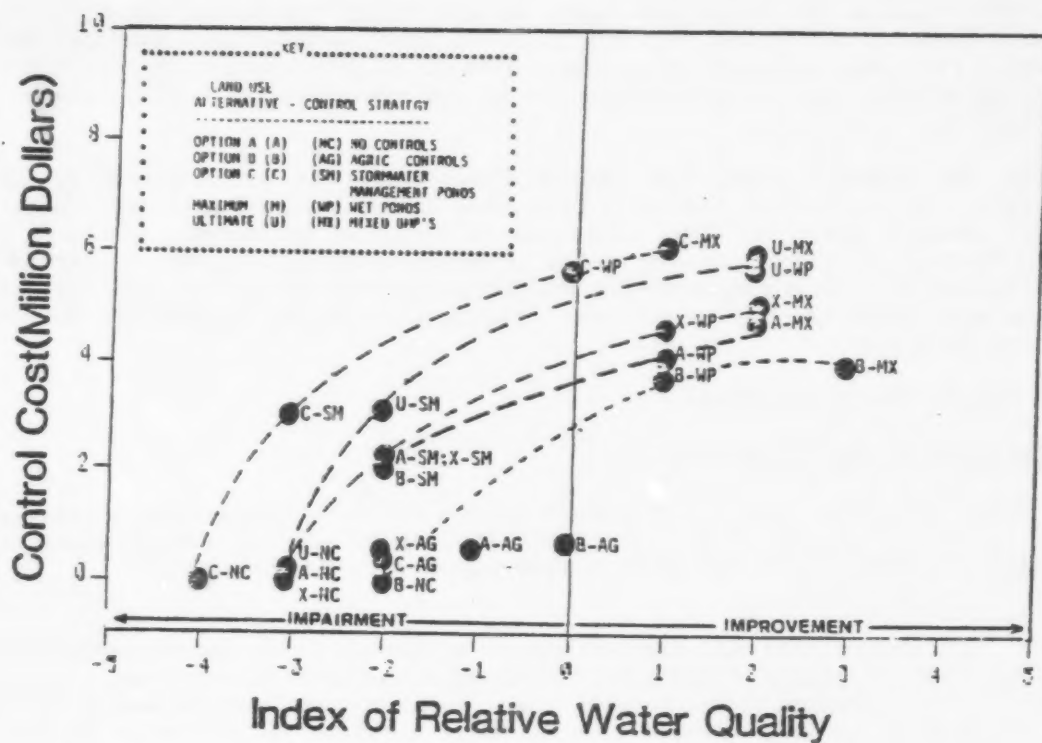
- Finally, preliminary efforts were made to identify some of the conceivable economic benefits which might arise from an effective watershed management strategy. This was done in qualitative terms in most cases, since the quantification of the benefits of stream protection remains one of the most problematic aspects of resource economics at the present time.

### Study Integration

The last phase of the prototype watershed planning process involved distilling the monitoring and modeling results into a series of recommended management strategies. Previous steps in the series progressively screened the full range of control scenarios and land use planning alternatives on the basis of relative efficiency and cost. Rather than advocate a single approach to watershed management, it was felt that a diversity of management approaches could be applied in each watershed. Therefore, management recommendations were oriented towards identifying universal features which might be incorporated into the fabric of any watershed plan. Emphasis was also placed on examining institutional factors and mechanisms which could strongly influence the implementation of a plan.

Conducting the watershed planning effort to the scale of that outlined for the six stage prototype planning process is not a technically simple or inexpensive task. The financial, staff and computer resources required are extensive. Obviously, such an intensive planning approach is probably only justified in those watersheds which contain the most beneficial uses and also are likely to experience the greatest adverse impacts. Nonetheless, many of the management implications generated by the study can be applied in a general manner to most of the other local watersheds, i.e., as a management tool for testing the effectiveness of general management approaches for dealing with the urban runoff problems.

Figure 6.9  
COST-BENEFIT CURVES ASSOCIATED WITH VARIOUS CONTROL  
OPTIONS AND FUTURE LAND USE SCENARIOS IN THE  
CLARKSBURG PLANNING AREA



#### Land Use Planning Alternatives

Maximum: Maximum development option (80%)

Option A: Downzoning to rural residential and open space

Option B: Downzoning to open space/agricultural preservation

Option C: Option A with a high tech industrial corridor

Ultimate: Outdated master plan (90% dev.)

## SENECA CREEK WATERSHED STUDY FINDINGS

The Seneca Creek watershed drains an area of approximately 129 square miles. This watershed is located completely within the Piedmont Plateau, an area characterized by gently to steeply rolling topography. Elevations within the area range from 950 ft, above sea level (MSL) in the northeastern section to 180 ft MSL at the mouth of Seneca Creek at its confluence with the Potomac River. Soils found within the Seneca drainage area are typical of those common to the Piedmont Plateau, having been derived, in part, from the underlying igneous, metamorphic and older sedimentary bedrock. Most of the soils within the basin are well drained silt loams which exhibit low to moderate runoff rates in response to rainfall.

At the present time, the Seneca Creek basin is primarily rural in character. Nearly half of the basin is devoted to agricultural uses and over 25 percent remains forested. This situation is expected to change considerably during the next 20 years, however. This transformation will include conversion of extensive areas into single family and medium density residential housing, as well as more intensive commercial uses. Projected land use changes are summarized in Table 6.3.

### Water Quality Monitoring Phase

#### Evaluation of Current Conditions

While some water quality indicators remain well within acceptable limits, other indicators suggest that the overall quality of water in Seneca Creek is degraded, particularly in the lower reaches of the stream. For example:

- The well-shaded and aerated waters of Seneca Creek consistently met State standards established for dissolved oxygen and water temperature in all reaches of the stream. Also, the biological oxygen demand (BOD) exerted on the stream tended to be at moderate to low levels at most times of the year.
- Sediment loading appeared to be the most serious water quality problem in Seneca Creek. High rates of erosion coupled with increased channel scouring by storm water runoff produced persistently high sediment concentrations in Seneca Creek. High sediment loads and increased stormwater runoff volumes and velocities also significantly altered the main stream channel in many reaches, and may be an important causal factor in the deterioration of the stream's capacity to sustain a diverse aquatic habitat.
- Bacterial standards were consistently violated throughout the entire Seneca Creek drainage system. Extremely high fecal coliform counts have been routinely measured in tributaries draining both suburban and rural watersheds. In the mainstem of Great Seneca, violations of the state bacterial standard occurred in four out of every five measurements.
- Nutrient enrichment (eutrophication) is not usually considered to be a significant problem in free flowing streams such as Seneca Creek. Current nutrient levels, however, appear to be of sufficient magnitude to

Table 6.3  
EXISTING AND FUTURE LAND USE DISTRIBUTIONS  
IN SENECA AND PISCATAWAY CREEK WATERSHEDS

|                                          | EXISTING<br>(%) | FUTURE<br>(MAXIMUM DEVELOPMENT)<br>(%) | NET %<br>CHANGE |
|------------------------------------------|-----------------|----------------------------------------|-----------------|
| <u>Seneca Creek</u>                      |                 |                                        |                 |
| Forest                                   | 25              | 15                                     | -11             |
| Crops                                    | 25              | 10                                     | -16             |
| Pasture                                  | 29              | 12                                     | -17             |
| Low Density<br>Development <sup>a</sup>  | 13              | 37                                     | +24             |
| High Density <sup>b</sup><br>Development | 6               | 26                                     | +20             |
| <u>Piscataway Creek</u>                  |                 |                                        |                 |
| Forest                                   | 49              | 1                                      | -48             |
| Crops                                    | 13              | 0                                      | -13             |
| Pasture <sup>c</sup>                     | 19              | 5                                      | -14             |
| Low Density<br>Development               | 11              | 84                                     | +73             |
| High Density<br>Development              | 8               | 10                                     | + 2             |

<sup>a</sup>Includes rural residential and low density residential land use.

<sup>b</sup>Includes medium density and high density residential land uses in addition to commercial/industrial.

<sup>c</sup>Includes open space.



create eutrophic conditions in existing water impoundments throughout the Seneca basin. In particular, nitrate and total phosphorus concentrations were found to be higher than those reported for other similar streams in the Maryland Piedmont.

- Contamination of the stream by trace metals may be a cause for concern. At least seven trace metals violated one or more of the EPA water quality criteria for the protection of aquatic life, human health or human welfare. Several metals -- iron, silver, copper and lead -- violated EPA criteria with a 20 percent or greater frequency.
- The low buffering capacity of Seneca Creek's soft waters leads to large fluctuations in the pH in the stream. pH levels vary by as much as 6 orders of magnitude, and fall below the 6.5 State Standard from 9 to 48 percent of the time.

#### Identification of Stream Impacts

Analysis of the long term water quality record indicated that current water quality and stream habitat conditions impaired several beneficial uses of Seneca Creek -- aquatic life, aesthetics, fishing, and other allied forms of recreation.

- As in many streams throughout the region, consistently high bacterial levels in the entire Seneca Creek drainage system appear to preclude the use of the stream for water contact recreation under present Maryland water quality standards.
- Stream waters in the lower reaches of Seneca Creek are turbid three out of every four days, on average. From an aesthetic standpoint, the discolored water and unsightly debris significantly detract from the recreational experience.
- Deterioration of water quality is often manifested in changes in the structure of the fish community. An analysis of historical fish survey records indicates that the abundance, diversity, and composition of the fish community has changed over the last sixty years. Major elements of the change are: 1) the disappearance of game fish from the mainstem of Great Seneca; 2) an increase in the number of species with a rare or extremely rare abundance; 3) profound changes in the composition of fish species typified by the replacement of environmentally sensitive species by hardier ones; 4) substantial loss of fish diversity at the Mouth of Seneca and in Long Draught Branch; 5) constant or slightly declining diversity in Little Seneca; and 6) an increase in fish diversity in the mainstem of Great Seneca.
- Historical changes in the structure of the fish community appear to be as much a response to habitat deterioration than changes in overall water quality. Deterioration of habitat can be attributed to deposited sediments and the effect of imperviousness in creating unstable flow regimes.
- Nutrients and sediment generated within the Seneca watershed and eventually delivered to the Lower Potomac River, an estuarine system where

eutrophication has been a persistent concern. While Seneca Creek contributes only a small fraction of the total annual pollutant load to the Potomac River at the Fall line, it is estimated that four times as much total nitrogen, five times as much total phosphorus, and six times as much sediment are transported on a per acre basis, when compared to the average per acre loading of the combined upper Potomac basins.

### Model Application Phase

The Seneca watershed study placed particular emphasis on the analysis of projected water quality impacts and nonpoint pollution management options in the Clarksburg Planning Area. The Clarksburg area was selected for special attention because it included the entire upland drainage to the Little Seneca reservoir, an emergency water supply reservoir under construction. Also, streams in the watershed provide support to one of Montgomery County's most diverse fish communities. It was felt that this study could provide relevant information on likely changes in water quality and stream habitat associated with land use options for timely incorporation into the master planning process.

### Selection of Control Strategies

Modeling efforts concentrated on determining the watershed impacts of the following control measures (which were selected by local planners and agencies):

1. Non structural land use planning measures emphasizing preservation of open space.
2. Conventional "dry" stormwater ponds (for peak runoff control).
3. "Wet" stormwater ponds for peak runoff and nonpoint source control (including extended detention designs for highly impervious land uses).
4. Comprehensive agricultural best management practices (BMP's) for control of agricultural runoff.
5. "Wet" ponds and agricultural BMP's.

Comparisons for each land use/runoff control combination impact were developed in terms of simulated changes in peak stream flows, dry weather flows, minimum dissolved oxygen levels, nutrient, sediment and BOD loads, stream bank erosion, channel deposition, and reservoir chlorophyll "a" levels.

### Impacts of Future Development Without Runoff Controls

In the absence of stormwater and nonpoint source controls, all of the Clarksburg master plan land use options were projected to have deleterious effects on both instream habitat and lake water quality, relative to existing conditions. In particular:

- Peak stormwater runoff discharges would increase by 20 to 40 percent.
- Dry weather low flows would be reduced by 10 to 25 percent.

- Streambank erosion would dramatically increase from 40 to 116 percent.
- The number of days that tributary streams would experience high levels of turbidity would rise by 13 to 23 percent.
- Loads of sediment, nitrogen and BOD delivered to Little Seneca Lake were projected to increase by 10 to 50 percent, depending on the land use scenario.
- Phosphorus loads, generated by existing and all future land use scenarios, were projected to produce eutrophic conditions in the lake. These conditions are often characterized by blooms of nuisance algae, dissolved oxygen deficits, odor problems and reduced water clarity.

### Comparative Effectiveness of Nonpoint Control Strategies in the Clarksburg Planning Area

#### 1. Land Use Planning Alternatives

Master plan alternatives calling for more intense development typically had the most severe impacts on stream habitat. These impacts included: increased peak discharge, diminished dry weather flows, higher streambank erosion rates and longer durations of high turbidity. On the other hand, the master plan alternatives which emphasized conservation of agricultural and forest lands, and were oriented towards lower density development, experienced less adverse impacts on stream habitat.

Conversely, planning alternatives which emphasized conservation of agricultural lands were projected to deliver nutrients and sediments to the lake in quantities which approached, and in some cases exceeded, those delivered in the more intensive development scenarios. This was largely due to the fact that agricultural loadings were normally higher than those from suburban areas. This suggests the need to couple agricultural preservation efforts with control of their nonpoint source loadings.

#### 2. "Dry" Pond Urban Stormwater Controls

The application of dry stormwater ponds would not prevent much of the projected deterioration of water quality and stream habitat associated with future development in the Clarksburg Planning Area. The principal purpose of these structures, flood control, would be effectively served. (i.e., peak discharges would be shaved considerably through much of the watershed.) However, under existing dry pond design criteria only minimal reductions in sediment and nutrient loads would be achieved. Also streambank erosion rates would only be marginally reduced. Similarly, no changes in dry weather low flow or duration of high stream turbidity levels were projected to occur. Finally, nutrient enrichment problems in the lake would not be noticeably diminished.

#### 3. "Wet" Pond Urban Stormwater Controls

This control strategy was projected to be very effective in mitigating many of the adverse effects of future development. Peak runoff discharges were reduced to below pre-development levels (i.e., existing conditions) and dry weather low flows were moderately augmented. Uncontrolled streambank erosion rates were reduced by 25 to 40 percent. Similar or greater reductions were projected

for basin wide nitrogen, phosphorus, and BOD loads delivered to the lake. Sediment loads were reduced by 15 to 35 percent. Projected algal levels in the lake declined by 5 to 14 micrograms/liter of chlorophyll "a", suggesting a significant potential for alleviating the potential eutrophication problem in the Lake.

#### 4. Agricultural Runoff Controls

This control scenario was patterned after the recently adopted SCS watershed conservation plan now in its first phases of implementation in Little Seneca. The program assumed the application of a wide variety of crop and pasture land management practices. Model projections indicated that the agricultural BMP controls were a very effective strategy in the land use scenarios where agricultural lands are retained in sizeable quantities. Most of the water quality benefits were associated with reductions in watershed nutrient, sediment and BOD loads, resulting in corresponding declines in algal and turbidity levels in the Lake.

#### 5. Combined Wet Pond and Agricultural Controls

The greatest degree of protection of lake water quality and stream habitat was realized when both urban and agricultural runoff controls were implemented together. In all but the most developed scenario, combined application of both controls resulted in both enhanced water quality conditions in the lake, and significant reductions in the deterioration of stream habitat, relative to existing conditions. Specifically, projected chlorophyll "a" concentrations within the lake were typically reduced by 40 to 60 percent. Chlorophyll reductions of this magnitude would prevent development of a eutrophic condition within the Lake. Sediment, nitrogen, phosphorus and BOD loadings are reduced to levels below those likely to be experienced under current land use patterns. Also, the flow regimes of the tributary streams (peak discharges and low flows) were not projected to change much from existing conditions. Streambank erosion rates in most scenarios were moderately reduced (25 to 45 percent.)

#### Economic Analysis Phase

The present worth of constructing and maintaining urban and agricultural stormwater controls measures within the Clarksburg Planning Area were as follows:

| CONTROL STRATEGY  | TOTAL COST<br>BASIN WIDE<br>(million dollars) | ANNUAL PAYMENT   |                    |                 |
|-------------------|-----------------------------------------------|------------------|--------------------|-----------------|
|                   |                                               | Dwelling<br>Unit | Commercial<br>Acre | Treated<br>Acre |
| DRY PONDS         | \$ 4.3 - 7.6                                  | \$14             | 236                | -               |
| WET PONDS         | \$ 9.4 - 14.3                                 | \$22             | 325                | -               |
| AG. CONTROLS      | \$ .07 - .66                                  | -                | -                  | 23              |
| COMBINED CONTROLS | \$10.1 - 14.4                                 | \$22             | 325                | 23              |

\*Note: Total capital and O&M amortized for twenty years at 8 percent.



Average annual residential payments for basin-wide dry and wet stormwater controls were estimated to be \$14-\$22 per dwelling Unit per year. Agricultural controls were estimated to cost \$23 per treated acre per year.

### Cost-Effectiveness Comparisons

Cost effectiveness comparisons were made which involved a direct comparison of the total basin-wide cost of a particular land use planning/control strategy combination with its relative effectiveness (as determined by its numerical ranking in a relative water quality index). Several combinations were identified which resulted in maintenance of, or improvements to, existing water quality conditions at a reasonable cost. These alternatives typically involved land use planning measures which emphasized conservation of open space, and were oriented towards lower density land use, in conjunction with basin-wide application of wet ponds and/or agricultural controls.

Three general conclusions emerged from the cost effectiveness analysis. First, agricultural control achieved more water quality benefits, per dollar spent, than any other control strategy. Secondly, wet ponds produced the most water quality benefits of all control measures, but are also the most expensive. Thirdly, dry pond controls designed only to attenuate stormwater peaks conferred only marginal improvements in water quality, relative to their high cost.

### Benefits of Runoff Controls

Although the economic benefits of an effective control program are difficult to quantify with any precision, some of the conceivable benefits included:

- Cost savings in the form of reduced dredging and disposal costs in the forebays and main reservoir of Little Seneca Lake.
- Protection of property and human life from flooding.
- Conservation of highly productive soils.
- Increased efficiency of basin farming.
- Recreational benefits from continued maintenance of a recreational fishery in tributary streams and Little Seneca Lake.
- Aesthetic benefits achieved by reducing the stormwater impacts to the channels of tributary streams and the eutrophication potential of Little Seneca Lake.

In this study, it was only possible to assign economic value to one of those benefits -- savings in sediment forebay dredging costs. Savings of \$129,000 to \$330,000 could be realized over twenty years if agricultural controls, wet ponds or both, were applied in the basin.

## PISCATAWAY CREEK WATERSHED STUDY FINDINGS

Piscataway Creek drains approximately 60 square miles. In contrast to the piedmont location of Seneca Creek, the Piscataway Watershed is located within the Atlantic Coastal Plain physiographic province. This area is underlain by the unconsolidated deposits of gravel, sand, silt and clay and characterized by gently rolling hills dissected by broad shallow valleys. Elevations within the watershed range from approximately 280 ft MSL in the northeast portion to sea level at the entrance of Piscataway Creek on the tidal Potomac River. The majority (53 percent) of the soils found within the drainage area are from the Sassafras-Croom Association. These are gravelly loam and sandy loam soils that produce moderately amounts of runoff in response to rainfall. The principal focus of the study was the 39.5 square mile area upstream of Piscataway Road (State Highway 223).

Forest is currently the predominant land use in the watershed and occupies nearly half the total acreage. Cropland and open space constitute approximately 25 percent of the total acreage. The remainder is a mixture of residential, commercial and industrial usage. Local planners have projected that the watershed will experience a significant amount of growth in low density residential developments during the next 20 years (Table 6.3).

Although the water quality monitoring and model testing aspects of the Piscataway Creek study were similar to those undertaken in Seneca, the model application phase was more restricted in scope. This was due to the preliminary stage of the land use master planning process and the limited number of runoff control options under active consideration at the time the study was undertaken. Some of the major activities, findings and conclusions of this watershed study are summarized below:

### Water Quality Monitoring Phase

The extensive sampling carried out on Piscataway Creek as part of NURP produced an assessment of water quality characterized by mixed results. On the one hand, indicators such as dissolved oxygen, BOD and nutrients did not appear to be causing any problems within the creek itself. On the other hand, however, pH, sediment and bacteria indicators were frequently at levels indicative of impaired water quality. The following conclusions were drawn from this part of the study:

- Dissolved oxygen concentrations remained close to saturation and above the Maryland standard of 5.0 mg/l at all times. This indicated a healthy situation that is principally due to the steep gradient of the creek and the absence of major waste loads in the watershed.
- Nutrients and BOD from nonpoint sources did not appear to be causing any serious water quality problems within free flowing section of Piscataway Creek.
- Fecal coliform concentrations were frequently in violation of state standards, especially during storms. This indicated that the threat of bacterial and/or viral contamination from both human and animal sources is present.

- Violations of the Maryland water quality standard for pH were recorded in nearly every other sample during the NURP study, indicating that the catchment produces rather acidic water quality conditions.
- Iron, lead, zinc, manganese, copper and nickel concentrations occasionally exceeded water quality criteria established by EPA for aquatic life and human health.
- Suspended sediment concentrations between 100 and 1000 mg/l during storms frequently persisted for durations well in excess of 24-hours.
- Streambank erosion is a serious problem along Piscataway Creek. Heavy deposits of sediment were found to be commonplace along the Creek during field reconnaissance.
- Piscataway Creek has, in the past, supported a highly diverse aquatic community that included anadromous fish. There is some evidence within the sediment and water quality data, as well as some visual evidence along the creek itself, that the ability of the creek to sustain a highly diverse community is currently impaired.

#### Model Application Phase

The ability of the watershed model to simulate the principal processes affecting basin hydrology, the generation and transport of nonpoint source pollutants and sediment, and instream water quality was demonstrated. The calibrated watershed model was applied to project hydrologic, water quality and sediment changes that would be expected to accompany future development in the watershed. Projections were based upon a planned land use situation under consideration by the Maryland-National Capital Park and Planning Commission. The major trend incorporated within this planned land use alternative is the conversion of most of the forest and virtually all of the agricultural land within the watershed to residential development of varying density. In terms of impervious cover, this translates to an overall increase from approximately 11 percent to 30 percent for the watershed.

Model projections were made based on the planned land use under the assumption that no nonpoint source controls would be constructed in association with new development. The results drawn from model projections of this "uncontrolled" situation are as follows:

- Model projections based on a "planned" future land use situation showed that stormwater, nutrient and sediment loads would increase substantially in the absence of appropriate urban runoff control measures. (Table 6.4)
- Stream bank erosion and channel scour were projected to increase dramatically unless controlled.
- Basin hydrology was projected to change significantly due to development and increased impervious cover. An increase in peak runoff rates, less infiltration and recharge of groundwater, and longer more frequent periods of zero flow could be expected.

Table 6.4  
WATER QUALITY AND QUANTITY PROJECTIONS IN PISCATAWAY  
CREEK UNDER DIFFERENT LAND USE SCENARIOS

|                                    | <u>PREDEVELOPMENT<br/>(100% FORESTED)</u> | <u>EXISTING<br/>CONDITION</u> | <u>PLANNED<br/>LAND USE</u> | <u>PLANNED<br/>(WITH CONTROLS)</u> |
|------------------------------------|-------------------------------------------|-------------------------------|-----------------------------|------------------------------------|
| Nitrate (lbs/yr)                   | 23,200                                    | 27,770                        | 30,660                      | 22,770                             |
| Ammonia (lbs/yr)                   | 7,980                                     | 10,630                        | 13,950                      | 6,960                              |
| Total Organic<br>Nitrogen (lbs/yr) | 96,600                                    | 137,400                       | 204,400                     | 169,500                            |
| Total<br>Phosphorus (lbs/yr)       | 44,100                                    | 68,130                        | 106,000                     | 67,300                             |
| Total<br>Sediment (tons/yr)        | 9,000                                     | 15,650                        | 29,510                      | 19,350                             |
| Net<br>Scour (ton/yr)              | 3,220                                     | 4,330                         | 12,690                      | 8,510                              |



- Future water quality in Piscataway Creek would principally be affected by increased turbidity and lower water clarity. The tidal receiving waters of Piscataway embayment and the Upper Potomac estuary were projected to receive larger annual nonpoint source loads of sediment and nutrients from Piscataway Creek which could contribute to existing problems related to eutrophication and the loss of submerged aquatic vegetation.

As a means of evaluating the effectiveness of nonpoint source controls, wet pond pollutant removal efficiencies were applied to runoff from areas expected to undergo development under the planned land use alternative. These "controlled" projections were compared with the previously described uncontrolled planned land use projections. The intent of this approach was not to advocate the use of wet ponds over other measures, but to demonstrate the maximum amount of control and reduction in loads that could be realized with a basinwide application of BMP's with new development.

The results of applying the model under these assumptions of nonpoint source control use are as follows:

- A large degree of control over the increases in loads projected under the "planned" land use situation ranging from nearly 100 percent for some nutrients to approximately 75 percent for sediment would be possible with the widespread application of Best Management Practices. These reductions in loads are summarized in Table 6.3 which shows four land use situations: predevelopment, existing, and planned land use both with and without controls.
- The use of management practices such as wet ponds could be implemented to provide flood control protection in addition to erosion control and other water quality benefits. Wet ponds would also provide for high levels of nutrient removal from runoff which would assist in the abatement of accelerated eutrophication in the Piscataway embayment and the Upper Potomac estuary.

### Economic Analysis

Since the planned land use scenario represents a very substantial increase in the amount of developed land beyond what is currently in existence, a large number of wet ponds would be required. For the sake of uniformity it was assumed that off-site wet ponds would be used exclusively, with each 150 acres of new development requiring a pond. Basinwide implementation of wet ponds with new development would require an estimated 114 ponds to accommodate the runoff from low density residential development. In addition, another 12 ponds would be needed to handle stormwater from the more densely developed residential, commercial and industrial land uses. The estimate of total construction cost for all of the ponds was nearly \$9.5 million. The annual operation and maintenance costs for all 126 of the ponds was estimated to be about \$380,000. These calculations are summarized on Table 6.5. It should be noted that these costs are associated with a land use alternative that is characterized by nearly complete development within the watershed.

The cost study also provided some guidance on the relative cost (construction plus O/M) per dwelling unit. Annualized total project costs per

dwelling unit vary by density and would be approximately as follows: \$73 per year for low density residential development; \$22 per year for medium density residential development; and \$9 per year for townhouse/garden apartment developments. In addition, the annualized cost for commercial development was estimated to be approximately \$112 per acre.

Table 6.5  
COST OF RUNOFF CONTROLS IN THE PISCATAWAY CREEK WATERSHED

STORAGE AND COST ESTIMATES FOR OFF-SITE WET PONDS

Basinwide Costs

|                                                    |                      |
|----------------------------------------------------|----------------------|
| . Total Construction Costs                         |                      |
| low density development<br>(114 ponds @ \$72,000)  | : \$8,208,000        |
| high density development<br>(12 ponds @ \$104,000) | : \$1,248,000        |
| Total Construction Costs                           | : <u>\$9,456,000</u> |
| . Total Annual O&M                                 |                      |
| low density development<br>(114 ponds @ \$2,900)   | : \$330,600          |
| high density development<br>(12 ponds @ \$4,150)   | : \$ 49,800          |
| Total O&M Costs                                    | : <u>\$380,400</u>   |

## REGIONAL IMPLICATIONS OF PROTOTYPE WATERSHED STUDIES

Future development trends suggest that urban runoff may eventually become an important factor in the quality of surface waters throughout the region. The best available estimates suggest that urban development may increase by nearly 50 percent throughout the Washington metropolitan area between now and the turn of the century (MWCOC, November 1979). Without effective runoff controls, local experience has shown that development of this magnitude can be expected to induce undesirable changes in the quality and quantity of surface waters throughout many of the 42 major regional watersheds. Also, the increased level of urbanization may have adverse effects on the beneficial uses of downstream receiving waters, particularly with respect to nutrient enrichment.

Over the past decade, local governments have begun to recognize the need for urban stormwater controls. In most area jurisdictions, this had led to the adoption of stringent stormwater management policies and the encouragement of pre-development planning measures. Although the nature of public stormwater management policies varies substantially among area jurisdictions, (Table 6.5) the regional commitment of resources to stormwater management has been extensive. Nearly 3100 structures have been installed in the Washington area since the early 1970's. (Table 6.6) A recent regional survey (MWCOC, August 1983b) indicated that nearly 200 stormwater structures were either approved or installed during 1982. Collectively, these structures controlled the runoff from an estimated 4.5 square miles of new urban and suburban development. The total area controlled by these structures represented 75 percent of all new residential and commercial development which took place during the year, based on best available estimates.

Most of the stormwater structures built in 1982 (over 75 percent) were conventional stormwater detention ponds, which function primarily to attenuate peak flows and reduce downstream bank erosion. There was a definite trend towards the design and installation of multi-purpose stormwater structures that provide water quality protection in addition to water quantity control. Approximately 20 percent of the stormwater structures built in 1982 were of this variety. The trend toward multi-purpose structures represents a shift in direction in regional stormwater management away from exclusive control of water quantity towards more consideration of water quality protection. As the scope of regional stormwater management widens, more information on the effectiveness and costs of such an approach will be required. In this respect, many of the conclusions reached during the Seneca and Piscataway Creek watershed studies have larger applications to regional urban runoff management issues. Some of the potential regional implications of these studies are shown below.

- Uncontrolled urbanization is likely to have highly deleterious impacts on instream habitat and receiving water quality throughout the region. In particular, it is anticipated that uncontrolled stormwaters will produce increased rates of streambank erosion, elevate instream suspended sediment concentrations and lead to "flashy" streamflow regimes (typically characterized by increased peak discharges and reduced dry weather flows). The combined effect of these physical alterations of stream conditions can lead to the deterioration of aquatic habitat. With respect to impacts on receiving waters, the nutrient loadings associated with urban runoff have been shown to have a significant potential for inducing highly eutrophic conditions in standing waters.

Table 6.6  
GENERAL FEATURES AND TRENDS OF PUBLIC STORMWATER  
MANAGEMENT PROGRAMS IN THE WASHINGTON AREA

**Alexandria.** Conforms to flood control requirements of the Corps of Engineers Four Mile Run project. Also reviews development proposals for locations throughout the city. The number and size of stormwater structures implemented are small, reflecting the lack of new sites for development in this urban area. Maintenance and site inspections are frequently conducted. Trends indicated are towards wet ponds, control of larger areas. No trend toward off-site ponds.

**Arlington County.** Since 1976, all development draining to the Potomac is required to provide stormwater management. Pre-development runoff rates must be maintained. The County is also involved in the Four Mile Run Management Program, which uses a NVPOC computer model to define SWM needs. As with Alexandria, space limits development and most ponds are very small (< 1 acre drainage). There is a slight trend toward pond designs which enhance nonpoint control; no trend towards wet pond construction.

**District of Columbia.** The City has no formal regulatory requirement for stormwater management. Provisions in the D.C. Sediment and Erosion Control ordinance do, however, allow conversion of temporary sediment basins to permanent stormwater management ponds. Only a few SWM structures have been built in the city to date because the majority of land in D.C. was developed before control of stormwater became a concern of local governments.

**Falls Church.** Falls Church is a member of the Four Mile Run Management Program, and has required SWM structures for flood control purposes. No trends towards control of larger drainage areas, wet ponds, off-site ponds. BMP oriented pond designs, or public maintenance reported by city officials. All structures built to date have been "dry" ponds or detention chambers.

**Fairfax County.** Has been seeking BMP proffers (which include runoff quantity and quality controls) for all new development. County Board of Supervisors has adopted legislation requiring the use of BMPs in the Fairfax portion of the Occoquan Basin. Wide diversity of stormwater and BMP structures have been installed in the County. Fairfax inspects stormwater facilities every two years, and has maintenance agreements between local governments and private developer. Most structures service small drainage areas, but there appears to be a trend toward off-site ponds.

**Loudoun County.** Encourages SWM controls as specified by State standards. Trends towards moderate sized pond structures, some of which (20%) have permanent water storage.

**Manassas.** City of Manassas has instituted a comprehensive stormwater management policy. The City has a program to collect \$1,500/acre from developers for construction of off-site ponds, (in lieu of on-site development) in addition to on-site ponds. Noted trends are toward control of larger drainage areas, wet ponds, off-site ponds, ponds which enhance nonpoint control, and public maintenance. City undertakes frequent site inspections and performs regular maintenance.

**Montgomery County.** The Montgomery County Council has passed a model ordinance requiring the installation of either on-site or off-site flood control and water quality management structures to control stormwaters from developed lands. Maryland National Capital Park and Planning Commission performs detailed studies of major county watersheds to define runoff and water quality control needs in the land use planning process. Waivers of on-site requirements with contribution to county regional off-site fund are common. Maintenance easements are obtained from developers. SWM review process is conducted with local Soil Conservation District, which requires pond structures. Trend appears to be towards control of larger drainage areas, off-site facilities, wet ponds and assumption of public maintenance.

**Prince William County.** The County has both a Stormwater Management and Best Management Practices requirement for new development, particularly in the Prince William portion of the Occoquan Reservoir watershed. Structures approved are diverse in size and nature. County performs site inspection and occasional maintenance. Trends have been observed towards control of larger drainage areas, larger pond size, and developer contributions to public stormwater programs.

**Prince George's County.** A joint committee composed of all agencies involved in the development process reviews subdivision applications to determine SWM needs. Also, interagency watershed technical committee develops comprehensive watershed management plans for County. Emphasis on flood and sediment control. There appears to be no major trend toward water quality control. County has future plans for large regional instream flood control ponds. An overall trend to larger, off-site ponds is observed.

**Rockville.** Active program along same lines as Montgomery County, including public assumption of maintenance, and frequent site inspections. The present trend is toward larger drainage areas, off-site ponds, pond designs with enhanced nonpoint pollution control, developer contributions to off-site ponds in lieu of on-site development.



Table 6.7  
REGIONAL PROGRESS IN STORMWATER MANAGEMENT: 1982

| LOCAL JURISDICTION                        | ESTIMATED NUMBER OF STORMWATER STRUCTURES CONSTRUCTED SINCE ADOPTION OF CONTROL REQUIREMENTS | NUMBER OF NEW STORMWATER STRUCTURES APPROVED OR INSTALLED DURING 1982 | AVERAGE DRAINAGE AREA SERVED BY STORMWATER STRUCTURE (Acres) | ESTIMATED PERCENT OF STRUCTURES THAT ALSO SERVE AS RAIN-GUTS (1982) |
|-------------------------------------------|----------------------------------------------------------------------------------------------|-----------------------------------------------------------------------|--------------------------------------------------------------|---------------------------------------------------------------------|
| Montgomery County                         | 1000                                                                                         | 50                                                                    | 11-25                                                        | 10                                                                  |
| Prince Georges Co.                        | 1000                                                                                         | 6                                                                     | 1-5 (on-site)<br>>100 (off-site)                             | 0                                                                   |
| Rockville (included as part of Mont. Co.) | 32                                                                                           | 6                                                                     | 1-5 (on-site)<br>26-50 (off-site)                            | 5                                                                   |
| Alexandria                                | 20                                                                                           | 6                                                                     | 1-5                                                          | 15                                                                  |
| Arlington County                          | 150                                                                                          | 10                                                                    | >1                                                           | 20                                                                  |
| Falls Church                              | 30                                                                                           | 2                                                                     | 1-5                                                          | 0                                                                   |
| Fairfax County                            | 1000                                                                                         | 23                                                                    | 1-5                                                          | 20                                                                  |
| Fordham County                            | 10                                                                                           | 6                                                                     | 26-50                                                        | 20                                                                  |
| City of Housess                           | 10                                                                                           | 6                                                                     | 50-100                                                       | 60                                                                  |
| Prince William Co.                        | 325                                                                                          | 36                                                                    | 20                                                           | 10                                                                  |
| District of Columbia                      | N.E.                                                                                         | N.E.                                                                  | N.E.                                                         | N.E.                                                                |
| REGIONAL TOTALS                           | 3065                                                                                         | 203                                                                   | 13<br>(weighted average)                                     | 20%<br>(weighted average)                                           |

(a) Figures were derived from responses to the 1982 COC Stormwater Management Implementation Survey.  
N.E. = No estimate

Contamination of runoff by trace metals and bacteria may also serve to limit beneficial uses of receiving waters as well.

- Both the water quality and quantity impacts of urban runoff can be effectively mitigated through the use of stormwater control structures with high pollutant removal capability. In both Seneca and Piscataway watershed application of "wet" stormwater ponds was projected to result in overall water quality conditions which were equivalent or superior to levels currently experienced. By way of contrast, traditional "dry" stormwater management ponds exhibited little capacity to prevent future deterioration of instream habitat or receiving water quality. Thus, from the standpoint of efficiency, it would appear that existing stormwater management design criteria should be modified to allow for enhanced pollutant removal. Although only one such modification (wet ponds) was actually examined in the context of the watershed modeling efforts, previous NURP research has identified several other promising candidates such as extended detention or prolonged infiltration (Chapter 2).
- The success of a water quality oriented stormwater management program is dependent on widespread application, full compliance and continuing maintenance. Model projections in each watershed provide strong evidence that a limited, poorly maintained, or otherwise incomplete application of controls will not be effective on a watershed-wide basis. Also, the importance of early planning on the part of local officials cannot be over-emphasized. Both watershed studies have shown that pre-development planning, in concert with watershed monitoring and modeling, can provide timely guidance on cost-effective means of controlling urban runoff before it becomes a major problem. As local experience has often suggested, urban runoff is much easier to manage before development begins, than after it has finished.
- Both the Seneca and Piscataway Creek watershed studies demonstrated that land use planning alone is not sufficient to eliminate the adverse effects of urban runoff. Planning measures which are oriented towards preserving agricultural and forest lands, and emphasize lower density development do have significant potential for mitigating stream impacts. However, the greatest overall level of watershed protection is realized when land use planning measures are combined with effective runoff controls.
- Control of the nutrient and sediment loadings from agricultural lands is a key element in any comprehensive nonpoint source control strategy in transitional urbanizing watersheds. Although agriculture activities may occupy a decreasing share of the total acreage, unit area nonpoint loads are often higher than urban or other substitute uses. Agricultural BMPs can be very effective in curtailing nonpoint loadings, and as the analysis in Seneca Creek has shown, are extremely cost effective in comparison with structural urban BMPs.
- From the standpoint of comparative costs and benefits, both watershed studies provided strong evidence that water quality oriented urban BMPs, such as wet ponds, are probably a more attractive social investment, than traditional "dry" stormwater management structures. For a modest increase in cost (approximately 20 to 50 percent), significant

improvements in both water quality and quantity are realized when wet ponds are implemented. When fully applied to new development throughout a watershed, model projections indicate that wet ponds can reduce the water quality impacts of urbanization to levels which approach existing conditions. Model projections also suggest that when wet ponds and agricultural BMPs are applied in concert with land use planning measures (e.g., lower density zoning, and conservation of open space), the greatest overall improvements in both water quality and quantity conditions are likely to occur.

## REFERENCES

- Anderson Nichols Inc. 1982. "Application Guide For Hydrological Simulation Program - Fortran (HSPF)," Contract No. 68-01-6207, U.S. EPA, Environmental Research Laboratory, Athens, GA. 186 pp.
- Hydrocomp, Inc. 1981. "Users Manual For Hydrological Simulation Program - Fortran (HSPF)," EPA - 600/9-80-015, U.S. EPA, Environmental Research Laboratory, Athens, GA. 416 pp.
- Metropolitan Washington Council of Governments (MWCOC). May 1979. "Metropolitan Washington Urban Runoff Demonstration Project, Grant Application," Water Resources Planning Board. 216 pp.
- \_\_\_\_\_. November 1980. "Memo on Critical Watershed Selection Criteria." 15 pp.
- \_\_\_\_\_. April 1982. "The Seneca Creek Watershed Model: Documentation of the Hydrologic Calibration and Verification." 62 pp.
- \_\_\_\_\_. May 1982. "The Piscataway Creek Watershed Model: Documentation of the Hydrological Calibration and Verification." 62 pp.
- \_\_\_\_\_. August 1982. Water Quality in Seneca Creek: A Technical Assessment. 98 pp.
- \_\_\_\_\_. April 1983. Water Quality in Piscataway Creek: A Technical Assessment. 72 pp.
- \_\_\_\_\_. May 1983. "The Seneca Creek Model: Documentation of the Water Quality Calibration." 102 pp.
- \_\_\_\_\_. August 1983. Final Report on the Piscataway Creek Watershed Management Study. 120 pp.
- \_\_\_\_\_. August 1983b. Potomac River Water Quality 1982: Conditions and Trends in Metropolitan Washington, prepared for the Water Resources Planning Board. 116 pp.
- \_\_\_\_\_. October 1983. Final Report on the Seneca Creek Watershed Management Study, Volume I, Findings 146 pp.
- \_\_\_\_\_. November 1983. Final Report on the Seneca Creek Watershed Management Study, Volume II, Technical References.
- Occoquan Watershed Monitoring Laboratory (OWML) May 1983. Final Contract Report - MWCOC NURP, 316 pp.